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PRINCIPLES OF NAVAL ORDNANCE AND GUNNERY

Prepared by

BUREAU OF NAVAL PERSONNEL

NAVPERS 10783-A

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PREFACE

The principal purpose of this book is to serve as a classroom training text for NROTC and OCS students. It will also be useful to weapons department officer personnel as a reference and as a guide in the weapons aspects of shipboard organization, and as a convenient general reference in ordnance and gunnery for others.

This text is, however, not designed as an encyclopedia in this subject, nor is it intended to supersede or supplant official publications of the Chief of Naval Operations, the Bureau of Naval Weapons, the Bureau of Ships, or the Bureau of Naval Personnel will regard to doctrine, weapons and ammunition, shipboard organization, or shipboard operations. (See the official publications of these authorities on these matters.)

This course text occupies three volumes, of which this is the first. The first volume is concerned with all the weapons in current use in the U.S. Navy with the exception of guided missiles (and their control systems) and nuclear weapons. The second volume is devoted to guided missiles and nuclear weapons, and the third is a CONFIDENTIAL supplement to volume 2. The titles of these volumes are, respectively, Principles of Guided Missiles and Nuclear Weapons, and Navy Missile Systems—Confidential.

This course is specifically designed to meet the needs of NROTC and OCS students. To cover the complex field with which it is concerned, the text concentrates on elementary functional operation of complete systems, rather than on descriptive details of a wide variety of individual instruments. The book is not written for maintenance or repair personnel. Ordnance Pamphlets and other technical publications issued by the Bureau of Naval Weapons and the Bureau of Ships are available for all equipment discussed in this book. They should be consulted for detailed information.

The text and illustrations of this book were prepared by the U.S. Navy Training Publications Center, Washington, D.C., and reviewed by the Bureau of Naval Personnel; Bureau of Naval Weapons; by the Professors of Naval Science at the University of Pennsylvania; and by the Officer Candidate School, U.S. Naval Schools Command, U.S. Naval Station, Newport, Rhode Island.

1965 Edition

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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CHAPTER 1

INTRODUCTION TO NAVAL WEAPONS

A. Naval Weapons and Seapower

1A1. NAVY'S MISSION

Seapower is that portion of a nation's overall power which enables it to use the sea in furtherance of its interests, objectives, and policies. This definition implies two facets of control of the sea—control which permits the nation to use the sea as a highway open to itself and its allies, and control which permits the nation to prevent its use by the enemy or others.

Seapower rests directly on the armament of vessels (submersible and surface) and aircraft. The vessels and aircraft themselves can in the broad sense be considered vehicles whose function it is to deliver the weapons to the spot where they can be most effectively used. The naval power that can most effectively bring its airborne and waterborne weapons to bear in a given area of the sea or air, controls that area in either or both of the senses mentioned in the preceding paragraph. The United States Navy's mission is to do its part in providing for the security of the United States and to support the national policy throughout the world. Its primary way of accomplishing this is to gain and maintain command of the seas, to use the seas for the nation's purposes and those of its allies, and, in time of war, to deny use of the seas to an enemy.

B. Some Basic Terms Defined

1B1. ORDNANCE, GUNNERY, AND BALLISTICS

This text is concerned with the study of naval ordnance and gunnery. Together, the terms "ordnance" and "gunnery" embrace weapons and their use.

ORDNANCE comprises weapons and other physical equipment pertaining to them. All this is further classified as explosive ordnance, including such elements as gun ammunition, missiles, torpedoes, mines, bombs, rockets, and the like, and inert ordnance, which includes projecting devices (such as guns, launchers, and release gear), protective armor, and all the equipment needed to operate and control weapons. Aboard ship it refers to all elements that come under the general term "ship's armament."

Traditionally, gunnery is the art and science of using guns. Weapons is concerned with the practical use of all ordnance.

BALLISTICS is the science of projectile motion. (In this book, unless otherwise qualified, the term ballistics refers to the motion of projectiles fired from guns.) It falls naturally into two aspects; interior ballistics, which relates to the motion of the projectile within the bore of the gun, and exterior ballistics, which considers the action of the projectile in flight.

Each of these fields is the subject of careful and detailed study by specialists. Their findings are of enormous importance in gun design and in the development of fire control instruments. A general understanding of ballistics is essential to the naval officer afloat, so that he may achieve the best results with his ordnance equipment.

1B2. NAVAL WEAPONS AND ASSOCIATED EQUIPMENT

The weapons to be taken up in this course include:

GUNS. Essentially a gun is a tube closed at one end, from which a projectile is ejected at

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high speed by gases produced by a burning propellant. Guns may be used against surface or air targets.

ROCKETS. The essential component of a rocket is a propellant-filled tube equipped with a nozzle at one end. The burning propellant produces gases which are ejected through the nozzle; the rocket is driven by the reaction thrust developed.

GUIDED MISSILES. A guided missile is any unmanned vehicle moving above the earth's surface whose path can be changed by a mechanism within the vehicle. A ballistic missile is a guided missile designed to follow for a substantial part of its flight a ballistic (free or unsteered) trajectory.

AHEAD THROWN WEAPONS. These are explosive A/S (antisubmarine) weapons fired forward of the attacking surface vessel. They may be propelled by gunlike projectors or by rocket motors.

TORPEDOES. A torpedo is a self-propelled underwater explosive missile used against submarine and surface targets.

MINES. A mine is an underwater explosive weapon which in performing its function is not propelled, but is actuated when it is approached or touched by a target.

DEPTH CHARGES. A depth charge is an A/S weapon dropped or fired from surface vessels and designed to function either at a preset depth or in proximity to a submarine.

BOMBS. A bomb is any missile, other than torpedoes, mines, and guided missiles, that is dropped from an aircraft.

NUCLEAR (ATOMIC) WEAPONS. Nuclear weapons are explosive devices which obtain their disrupting energies from reactions in and between atomic nuclei. In context, the term special weapons means nuclear weapons.

RESTRICTED WEAPONS. These weapons include atomic, biological, and chemical types. Special doctrines apply to the use of these, and they are kept under the tight direct control of the President.

This volume does not cover nuclear (atomic) weapons or guided missiles; for these, see the next two volumes in this series.

The methods and devices used to control guns and other weapons or weapon launchers constitute fire control. With guns, fire control can be considered as the practical application of exterior ballistics to ensure that the projectile will hit the target. With nonballistic weapons, such as surface-to-air guided missiles, torpedoes, and mines, fire control comprises the control of weapon launchers and weapons so that the weapons will function on or in the close vicinity of the target.

SIGHTS are optical devices which establish the line of sight to the target and provide for positioning the gun so that its projectile will hit the target.

RANGEFINDERS are optical devices used to measure the distance or range to the target.

RADAR in ordnance equipment uses echoes of high-frequency radio pulses to establish continuous values of target elevation and bearing (this corresponds to the line of sight to the target) and target range.

GUN DIRECTORS incorporate optical sighting and (generally) radar equipment which establishes the location of targets and controls the positioning of guns so that their projectiles will strike the target. Gun directors may be located at some distance from the guns they control, or they may be quite close, depending on type and size, but they are generally higher in the ship's structure. Directors may or may not include computer equipment. Directors for missiles vary in design depending on the missiles with which they are used. Directors for torpedoes are associated with sonar equipment for underwater fire control.

FIRE CONTROL COMPUTERS OR RANGEKEEPERS are electronic or electromechanical devices into which are fed the mathematical variables in the fire control problem, and which yield solutions in the form of control settings required for the weapon and launcher to have maximum effect on the target.

STABLE ELEMENTS OR STABLE VERTICALS are gyroscopic devices which maintain a reference horizontal, independent of ship's pitch and roll, for use in the fire control problem solution.

DATA TRANSMISSION SYSTEMS are electrical lines and devices used for transmitting with optimum precision electrical signals corresponding to fire control information from one equipment component to another.

SONAR is the underwater analogy of radar; it functions by detecting echoes of pulses of ultrasonic sound, and furnishes range, bearing, and depth to targets.

WEAPON SYSTEMS. The naval officer today thinks of these weapons and associated equipment not as individual units but as weapon systems. NWP10A defines a weapon system as

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the combination of a weapon (or multiple of weapons) and the equipment used to bring the destructive power of the weapon against the enemy. It goes on to point out that maximum weapon capabilities are realized when associated units are conceived and developed by properly relating them to other elements in their operational environment.

The weapon system concept is relatively new and finds its most thoroughgoing application with newer weapons such as guided missiles. Although the formal recognition of the concept is recent, its implications have been understood for some time, and for this reason it is possible to consider certain combinations of weapons with other equipment as constituting a "system" even if the combination is not formally designated as such. The concept is therefore applied in later chapters of this book when, for example, the student takes up common combinations of gun directors, other fire control equipment, and gun mounts.

C. Organizational Responsibility for Ordnance

1C1. BACKGROUND

Any military organization must make some provision for the procurement of weapons, for supplying them with ammunition, for supplying them to personnel or installing them on vessels, vehicles, or aircraft, for keeping them in working condition, etc. These responsibilities are allocated to an organizational unit called an "ordnance department" or the equivalent.

In the United States military system, from the point of view of the Navy, these responsibilities are assigned most importantly at three levels—in the Department of Defense (for the entire military establishment), in the Navy Department (for the fleet and for shore facilities), and in the individual ship's weapons department. (These responsibilities appear also at other organizational levels, but are not taken up in this book.)

1C2. ORDNANCE RESPONSIBILITIES IN THE DEPARTMENT OF DEFENSE

The Department of Defense was created as a part of a program designed to provide for the future security of the United States through the establishment of integrated policies and procedures for the agencies of the Government concerned with the national security. Figure 1C1 is a simplified chart of the Department of Defense, emphasizing the relationships described below.

At the head of the Department of Defense is the Secretary of Defense, whose staff includes a number of assistant secretaries and others. (The Secretaries of the Army, Navy, and Air Force have a line relationship to the Secretary of Defense.) So far as ordnance is concerned, the most important member of the Defense Secretary's staff is the Assistant Secretary of Defense (Applications Engineering). This Assistant Secretary is concerned with engineering phases of development, design, and production of weapons and weapon systems, particularly with respect to military and engineering standards and characteristics, economy in use and maintenance, and production scheduling. The Assistant Secretary (Logistics) and the Assistant to the Secretary (Atomic Energy) are also concerned with ordnance matters—respectively as regards supply and atomic weapons. (For details on Defense Department organization, see the U.S. Government Organization Manual, issued annually by the General Services Administration.)

With respect to ordnance, as with other matters, the Navy functions as a member of a team which includes the Army and Air Force. Ordnance equipment is usually developed by and procured by the service primarily interested. However, there are hundreds of ordnance items used by all three services, or by at least two of them. For instance, the Navy and Air Force both use Army rifles and pistols; the Air Force carries Navy mines, and the Navy uses Air Force bombs; the Army uses some Navy projectile fuzes, and the Navy uses several Army rocket fuzes. When one service procures a device for another, it usually furnishes all appropriate spare parts, instructional materials, and special tools as well.

The Marine Corps and Coast Guard do not maintain ordnance departments. Except for a

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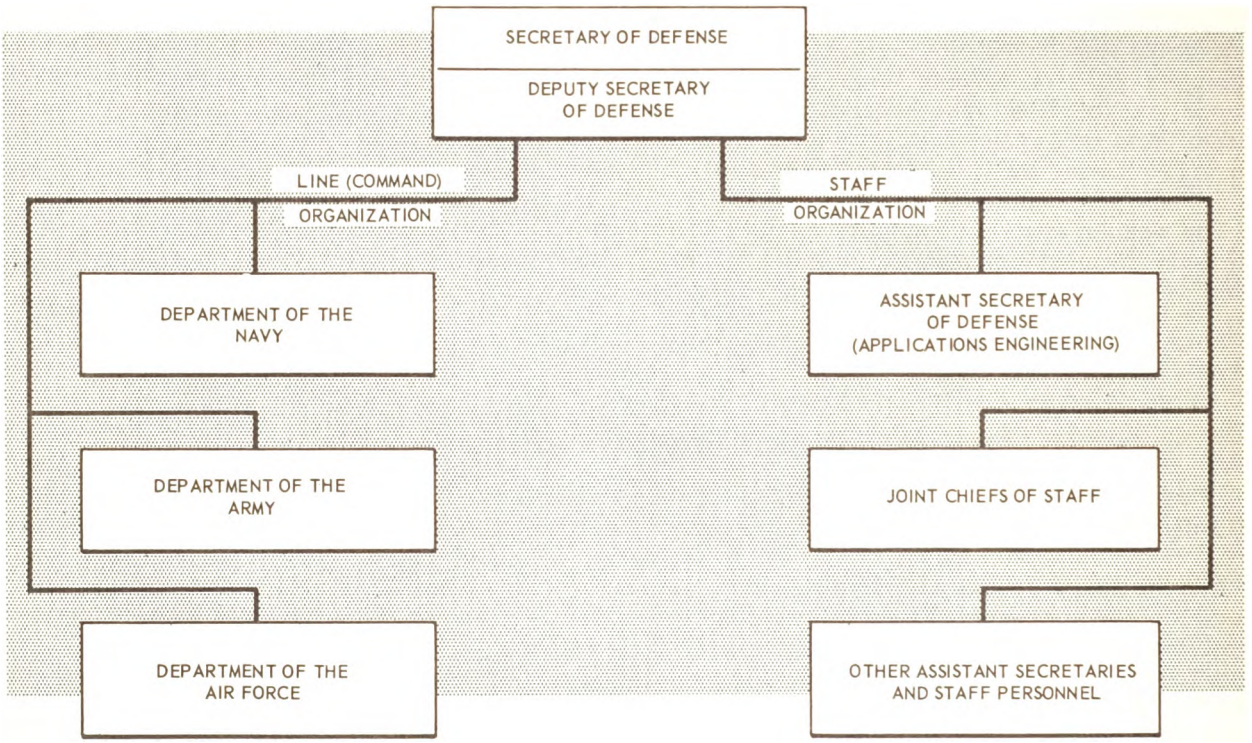

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Figure 1C1.—Organization of the Department of Defense.

few specialized items of equipment, they are dependent for their ordnance on the Army, Navy, and Air Force.

1C3. NAVY DEPARTMENT RESPONSIBILITIES FOR ORDNANCE AND GUNNERY

Within the Navy Department, the responsibility for ordnance material rests chiefly in the Bureau of Naval Weapons (BuWeps). Figure 1C2 shows the Bureau of Naval Weapons in the Department of the Navy Organizational structure. As defined by Navy Regulations, 1948:

"The Bureau of Naval Weapons shall be responsible for the following, except as otherwise prescribed in these regulations or by the Secretary of the Navy:

"The design, development, procurement, manufacture, distribution, maintenance, repair, alteration, and material effectiveness of naval ordnance; the research therein; and all pertinent functions relating thereto, including the control of storage and terminal facilities for, and the storage and issue of, ammunition and ammunition details."

The Bureau's responsibility includes ordnance material for ships and aircraft, and that used by Marine troops.

The Bureau of Naval Weapons in Washington is the executive authority of the Naval Ordnance Establishment, which consists of the Bureau itself and of activities under its management control. These activities include research facilities like the Naval Weapons Laboratory and the Naval Proving Ground, inspection facilities, storage and distribution facilities, and manufacturing plants like the Naval Propellant Plant (formerly Naval Powder Factory).

The Chief of Naval Operations (CNO) controls, through fleet and force commanders, the operational use of weapons, with appropriate liaison with the technical bureaus concerned. CNO also controls operational and team training in the use of weapons.

The Bureau of Naval Personnel (BuPers) is responsible for training of officers and enlisted

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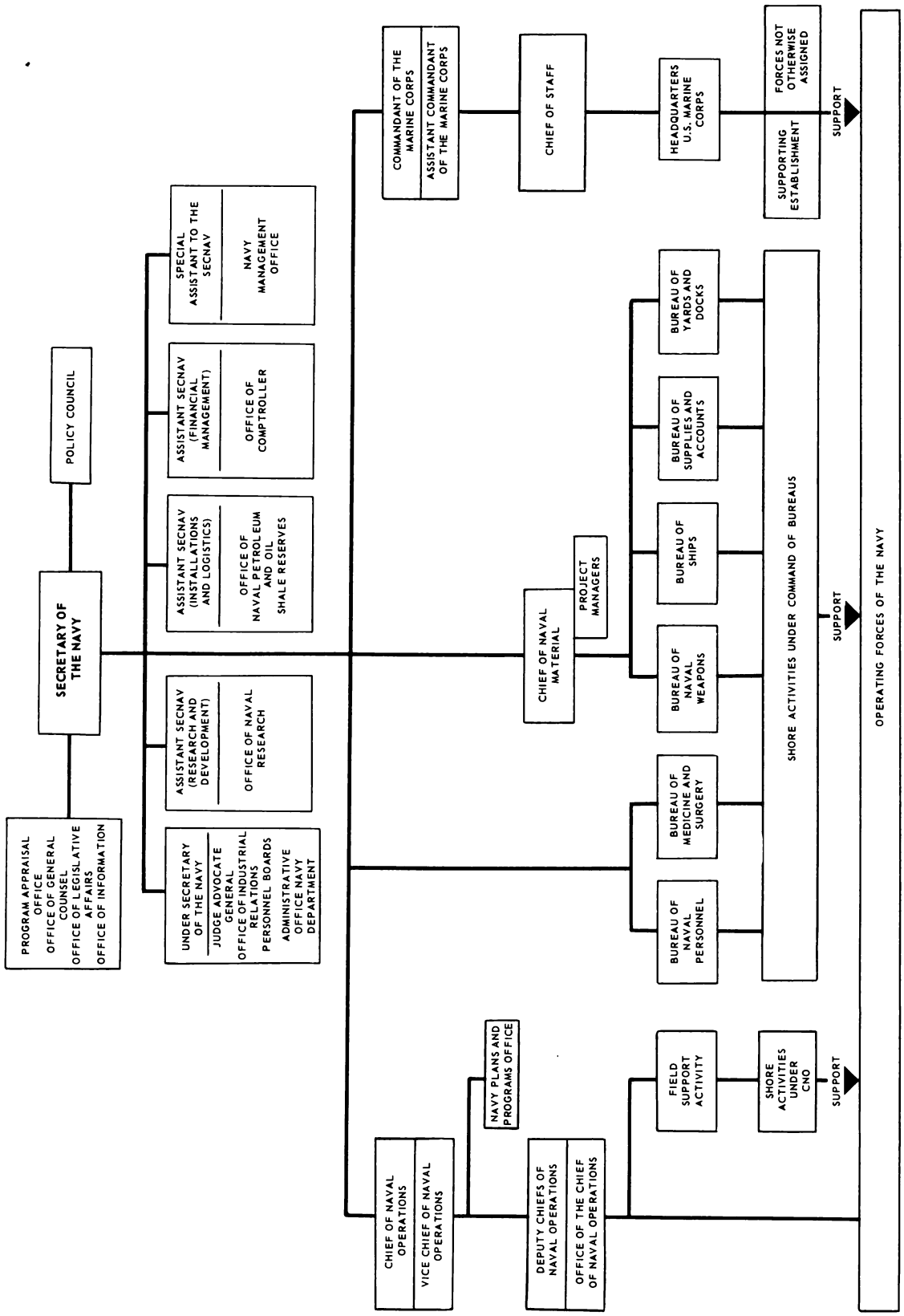

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Figure 1C2.—Organization of the Department of the Navy.

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men as individuals in the use and maintenance of weapons.

The Bureau of Ships (BuShips) is concerned with design problems in installation of ordnance in ships.

The Bureau of Supplies and Accounts (BuSandA) is responsible for the general fiscal management of the entire Navy (except personnel matters) including those aspects that are concerned with ordnance.

For full details concerning the relationship of each of the Bureaus with ordnance and gunnery, see the manual (one is published by each Bureau) that governs the organization and operation of that Bureau. The CNO Organization Manual performs the corresponding function for CNO.

1C4. FUNCTION OF THE SHIPBOARD WEAPONS DEPARTMENT

Naval ships are organized into departments, which are further broken down into divisions. In ships-of-the-line—that is, those ships which have been designed primarily to launch or fire weapons—the ordnance department is called the weapons department. The weapons officer is the head of this department. He is responsible for all of the ship's armanent, and its deck seamanship and related equipment. The weapons officer will have certain officer assistants within the department who direct their attention to specific weapons, equipment, and administrative matters. The duties of these weapons assistants are discussed in chapter 13. Notice in figures 1C3, 1C4, and 1C5 that the weapons departments consist of several divisions, each headed by an officer assistant who bears a title descriptive of his duties, e.g., Fire Control Officer, Missile Officer, etc. In figure 1C4 you can see that a division officer's job on a cruiser is a primary billet, but this same job may be a collateral duty on a destroyer, as shown in figures 1C3 and 1C5.

In ships whose offensive characteristics are not primarily related to ordnance or aircraft,

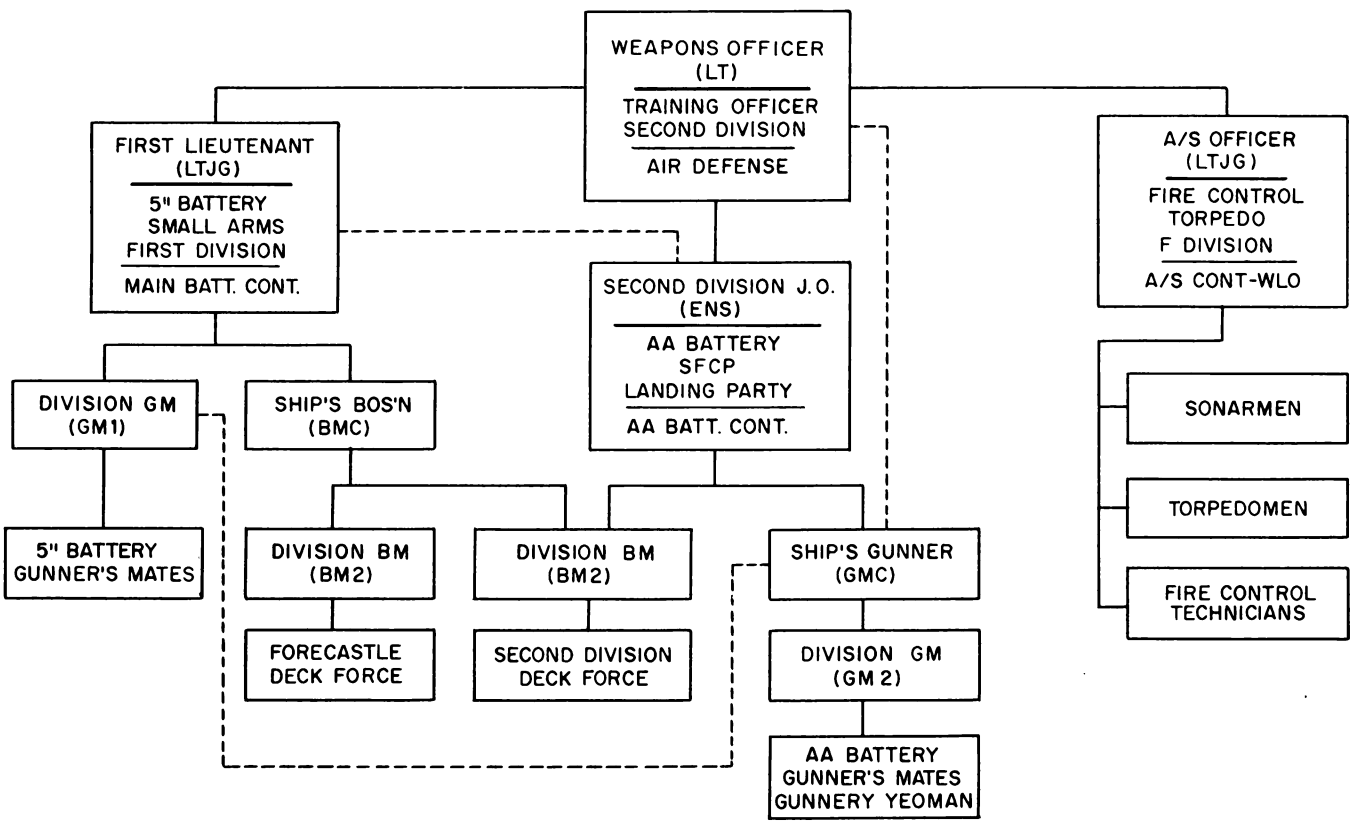

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Figure 1C3.—Weapons department organization for USS GEARING Class DD.

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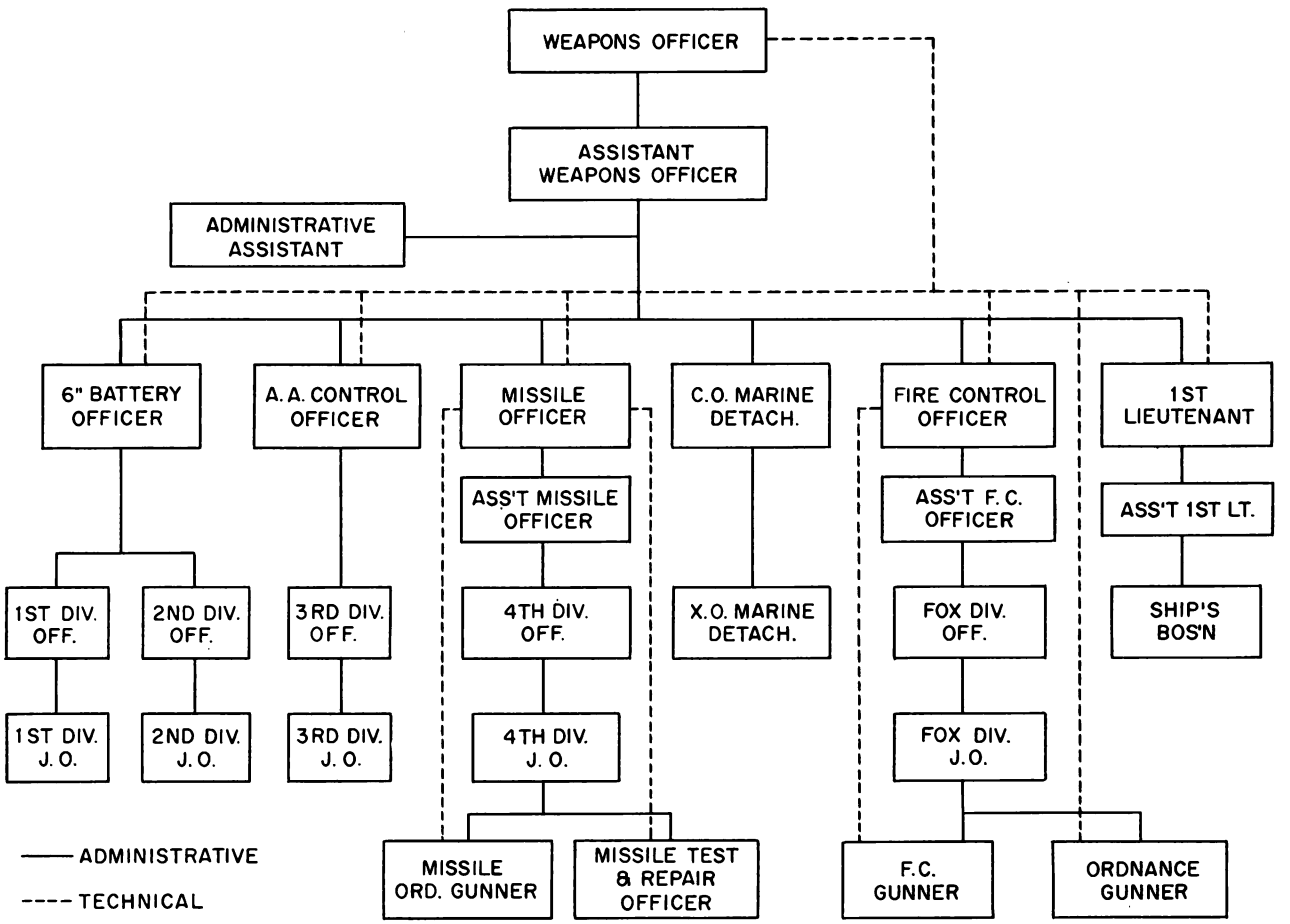

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Figure 1C4.—Weapons department organization for USS TOPEKA (CLG-8).

deck responsibilities will overshadow weapons. In such cases (usually auxiliaries and support ships) the first lieutenant is assigned as head of the department and as assistant for weapons. The weapons (or gunnery) officer is the assistant head of department, and the department will probably be called the deck department.

The details for weapons department organization must be separately established for each type of ship. Although there is considerable variation from one ship type to another, certain general aspects of organization apply to all ship types. There is a designated head of department (weapons officer, or first lieutenant) and he is assigned certain assistants. The number and titles of his assistants vary with the type of ship, its weapons installation, and the number of officers on board.

Further details on the organization and operation of the shipboard weapons department can be found in Navy Regulations, 1948; in Shipboard Procedures, NWP-50A; and in directives from the Chief of Naval Operations and type commanders.

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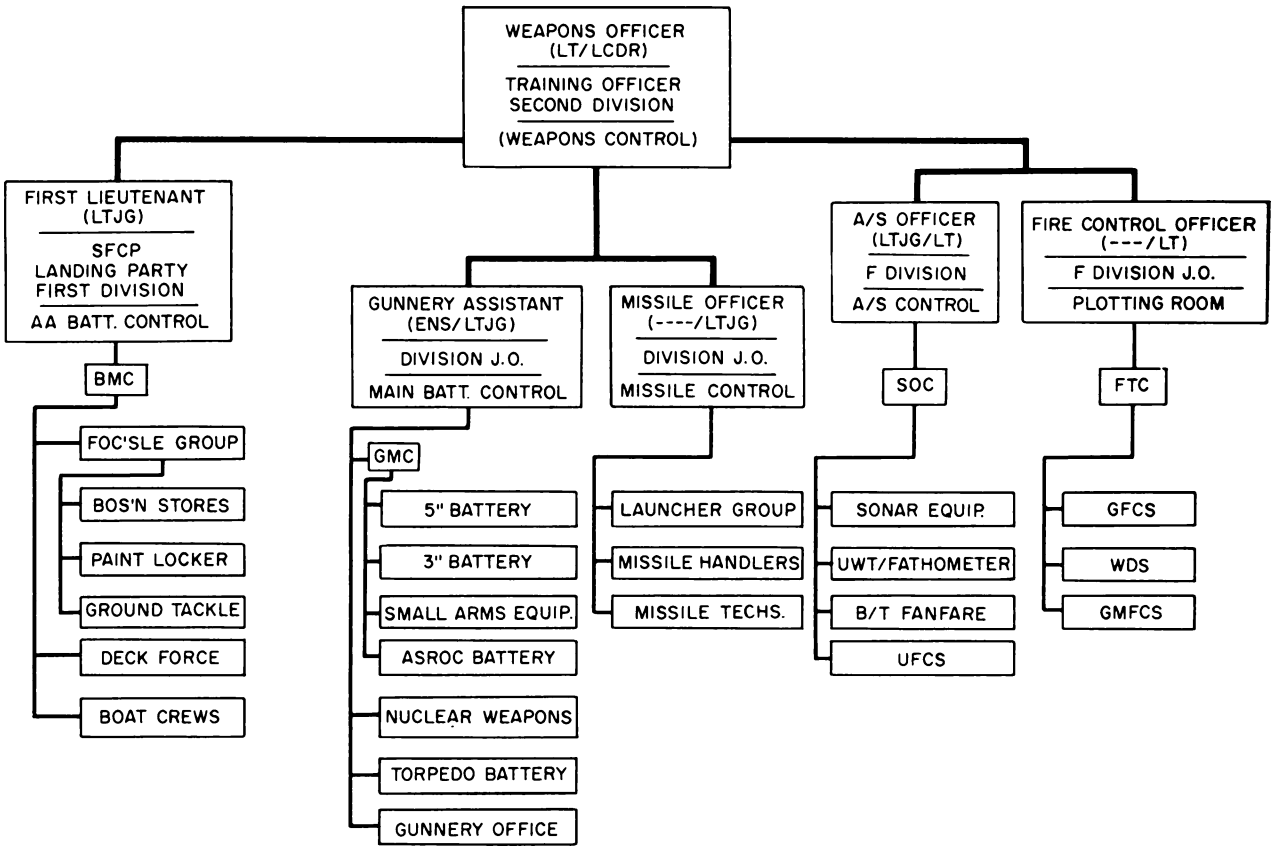

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Figure 1C5.—Weapons department organization for USS FARRAGUT Class DLG.

D. Identification of Ordnance Equipment

1D1. IMPORTANCE OF EQUIPMENT IDENTIFICATION

Never underestimate the importance of cataloging, classification, and nomenclature when dealing with ordnance. In fact, the word "ordnance" is related to the word "order," in the sense of arrangement or classification. Its use in connection with weapons has been traced back to England's Henry VIII, in whose reign the royal armanent was classified and cataloged.

Ordnance classification, cataloging, and standard nomenclature, which were a welcome innovation in the 16th century, became an unavoidable necessity in the 20th. In this course it will not be possible to describe in detail the complexities of U.S. naval ordnance cataloging and classification. This section will attempt only to explain enough to make the main principles clear.

1D2. NOMENCLATURE AND IDENTIFICATION

The standard nomenclature for any item of naval ordnance equipment includes a basic noun, often accompanied by descriptive adjectives, plus identifying numbers. Example: "3-in. 50-cal rapid-fire twin gun mount Mk 33 Mod 4." Reading this from left to right, "3-in." specifies the bore diameter or caliber, "50-cal" specifies the gun barrel length in terms of calibers (since

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this is a 50-caliber gun its length is 3x50 or 150 in.), "rapid-fire" indicates that its ammunition is fed into the gun automatically by a power-driven loader, "twin" indicates that the complete mount assembly incorporates two gun barrels mounted in parallel. The basic noun here is "mount," which here includes not only the gun barrels with their breech and recoil mechanisms, but also their training and elevating gear, gun mount shield, power drives, power rammer and loader, and fire control and sighting equipment located on the mount. "Mk 33 Mod 4" is abbreviated from "Mark 33 Modification 4," which specifies a particular version of a certain mount design.

In Navy usage, the modifiers in the nomenclature of a given item are flexibly used; thus, an ordnance technical manual (OP) may refer to the gun mount named above merely as "3-in. mount Mk 33 Mod 4." This represents the minimum. Note that the reference to "gun" is here omitted; when not otherwise specified, a mount is always a gun mount.

The mark number identifies a major item (like a gun mount) or principal component (like a sight or a power drive) of a particular design. When the Navy makes a basic change in design, or designs new equipment of the same general type, the name remains the same but a new mark number replaces the old. Thus the Mk 33 Mod 4 twin mount mentioned above has a different mark number from the generally similar Mk 34 single mount, and also a different mark number from the Mk 27 twin mount, which differs significantly from the Mk 33 in the design of the slide. The mod number (mod here stands for modification, not model) indicates a minor design change or alteration. For example, the Mk 33 Mod 4 mount mentioned above differs from Mod 2 chiefly in that Mod 4 has an aluminum shield while Mod 2 has not. Mods may be made also because of improvements in design based on experience, or to adapt the equipment for mounting in different places or for operation with different associated equipment.

The nomenclature of any naval gun barrel or mount always includes its caliber. There is a separate series of mark numbers for each caliber; for example, 3-inch and 5-inch gun barrels are numbered in different series. However, as long as the bore diameter is the same, gun barrels are numbered in the same series, regardless of bore length. Thus, both 5-inch gun barrels—the 5"/38, and the 5"/54 (and their mounts)—are numbered in a single series.

The mark and mod numbers, as well as the rest of the nomenclature, are assigned by the Bureau of Naval Weapons. The place to find this official nomenclature is the current edition of OP 0. (This publication is described later in this chapter.) For nomenclature of components or parts of units designated by mark and mod, use the OP or the ordnance supply catalog on the equipment.

Gun mounts are identified not only by mark and mod but also by assembly number. This is so because gun mounts (especially the larger ones) are not single units, but are really combinations of smaller units, each of which has its own mark and mod. For instance, the 5-inch Mount Mk 39 Mod 0 may be equipped with any one of a number of different mods of the Elevation Indicator-Regulator Mk 54, or with one of several mods of the Train Indicator-Regulator Mk 46. It may have either Mod 0 or Mod 1 of the Mk 54 shield, and so on. Each assembly differs from the other in details like this. Each assembly is, therefore, designated by an assembly number to distinguish it from the others.

Each individual unit of a given mark and mod has its own serial number. Identification by mark and mod is standard usage for weapons and fire control equipment. Some types of fire control radar use mark and mod designations, but most fire control radars, sonars, and other electronic equipment use a different system which is fundamentally composed of two groups of letter prefixes followed by an identifying number. An example is "Sonar equipment AN/SQS-4." Letter group "AN" means that the nomenclature complies with the system adopted jointly by the U.S. armed forces. In the following group, "SQS," the first "S" identifies the type of installation (it stands here for "water surface craft"), the "Q" stands for the type of equipment ("sonar and underwater sound"), and the final "S" indicates the purpose ("detecting and/or range bearing"). The numeral "4" serves as a model number, or the equivalent of a mark number. (However, modification numbers are not used in this system. Instead, a letter suffix "A," "B," etc., follows the model number.)

A complex electronic equipment like a sonar or radar system usually consists of several interconnected units. A letter group prefix is used instead of "AN/" to identify such a unit. For example, "IP-SQS-4" might be used to designate a cathode-ray display indicator tube used in conjunction with the AN/SQS-4 system.

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Navy ordnance equipment (such as small-arms weapons) and ammunition procured from the Army normally retain the Army model designation, which consists of the letter "M" (standing for model), followed by a number corresponding to mark number, then (if there are modifications) by the letter "A" followed by a number designating the mod. Thus "Carbine, cal .30, M3A1," identifies a certain carbine with a bore of 0.3 inch as what would correspond in Navy terminology to Mk 3 Mod 1.

Aircraft bombs which have been adopted jointly by the Air Force and Navy are identified by AN-followed by either Army style numbers (M__A__) or Navy mark and mod numbers.

1D3. NAMEPLATES AND OTHER MEANS FOR IDENTIFYING EQUIPMENT

Each item of equipment assigned a mark and mod number or equivalent bears a metal nameplate secured to some easily visible spot on its exterior. This plate is engraved or otherwise marked to provide the following information:

Standard nomenclature of the equipment, including mark and mod or equivalent, and identification of the system of which it is a part (unless it is an individual self-contained item).

Standard Navy Stock Number, Federal Stock Number, or other catalog identification.

Name of cognizant bureau (i.e., the Navy agency that procured the unit).

Manufacturer's part number or drawing number.

Name of manufacturer.

Number of contract under which the equipment was supplied.

Serial number, assembly number, or other numbers which identify the specific unit. Items produced in large quantities may have a lot number instead of a specifically assigned serial or other number.

The nameplate will probably also contain other information, such as the voltage and frequency of electric power to be supplied to the unit, precautions to be observed in using it, and blanks for recording alterations that have been made to the equipment. But the information listed above is approximately what you can normally expect to find. There will be some minor differences in equipment procured by different agencies of the Navy, but the nameplate will always be the best primary source for identification of equipment. It is obvious that the nameplate must never be detached, defaced, obliterated, or permitted to become illegible, either through neglectful accumulation of grime and dirt, through being painted over, or through overdiligent scouring that erases the information it contains. Nor may the information on it be changed or added to except as specifically directed by the cognizant technical bureau.

Many smaller assemblies and parts can be identified by numbers or coded markings. Numbers printed or engraved on parts or assemblies may be catalog numbers, Navy or contractor's drawing numbers, or code symbols that correspond to symbols on schematics. For most effective use of all of these, it is necessary to have available the technical manual or instruction book for the equipment, as well as, if possible, the appropriate part of the Navy's material catalog and available prints of the drawings on the equipment. With these, it is possible to establish positive identification of all parts and assemblies of the equipment.

The preceding paragraphs cover only the bare outline of the equipment identification and nomenclature systems used in the Navy. The subject is a complex one which can be completely mastered only by considerable specialized study.

In referring to a piece of ordnance, the information needed for identification depends upon the circumstances. For example, to identify the entire equipment as a functioning unit, the name, mark, and mod will be sufficient. But for requesting spare parts from the Ordnance Supply Office, the serial number (and the assembly number, if any) may be necessary in addition to the Federal Stock Number. These, together with mark and mod numbers, identify the specific unit involved which enables the supply officer to contact the manufacturer if necessary.

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E. Further Education in Ordnance and Gunnery

1E1. MIDSHIPMAN TRAINING (NROTC)

In a four-year NROTC program this course in naval ordnance and gunnery is planned for study during the sophomore year. During the summer following the completion of this course you receive a period of training in naval aviation. Your junior year course is devoted to naval engineering. During the summer following the completion of your junior year course you spend part of the summer on a training cruise aboard a naval ship. And your senior year is devoted to naval operations, naval administration, and elementary naval law.

Your chief opportunity for additional training in naval ordnance and gunnery up to the time you graduate will come during the summer cruise following your junior year. At this time you can expect a tour of training duty in the weapons department of a ship, quite likely aboard a destroyer or escort vessel, or possibly aboard a cruiser or carrier. This tour will give you experience in working as part of the weapons department at several different points. You will have an opportunity to serve in a number of general-quarters stations—in ammunition handling in gun mounts, in gun laying and firing, in fire control directors, in fire control or missile plot, in sonar and underwater battery plot, at torpedo and guided missile control stations, and elsewhere. This is where what you learn in this course will be translated into meaningful experience. To make sure that you are successful in your later career on active duty, you will have to make the most of this shipboard training, both in preparing for it and in doing the work aboard ship.

You will probably find that the subject matter of naval ordnance and gunnery is intrinsically interesting, particularly when you have the opportunity to work with the weapons and the equipment itself on board ship. But even if your primary area of interest is elsewhere, it is well to remember that all naval line officers have weapons department assignments sooner or later in their careers, and that it is worth working to make such assignments successful and profitable in terms of broadened background and increased knowledge and experience. Moreover, on your effectiveness as a member of the weapons department can depend the lives of your shipmates as well as your own.

Your tour following the sophomore year will also have potential value in connection with ordnance and gunnery training. It will afford an excellent opportunity for you to become familiar with airborne ordnance, such as mines, rockets, air-launched missiles, aircraft guns, dip sonar, and other antisubmarine gear.

1E2. UNDERGRADUATE TRAINING IN RELATED SUBJECTS

This course in naval ordnance and gunnery is to some extent self-contained in that it includes in chapter 3 the principles of mechanics, electricity, hydraulics, optics and sound in a form that makes them directly applicable later in this course. The basic material in this book and the mathematics and physics training that you have had represent only a bare minimum, and amplification of this minimum is strongly recommended. Valuable courses that would solidify the basis on which your naval training will be founded would include college chemistry, advanced mathematics through calculus, elementary drafting, elementary courses in electricity, electronics, nucleonics, mechanical engineering, and elementary aeronautical engineering (particularly with reference to guided missiles). Naturally, courses in all of these are not likely to be possible for most students, but any that you can take will be of great advantage. In planning your choice of technical courses, you would do well to consult with your Professor of Naval Science so that you can select courses of maximum value in your naval career.

1E3. TRAINING ON ACTIVE DUTY

It is a commonplace that education does not end when you receive your diploma. Like most commonplaces, it is true, and it is important. It applies to your naval career as well as to other aspects of your life, and it applies regardless of how you earned your commission.

When you are on active duty aboard ship, your professional education may be continued both on the job during duty hours and watches, and on your own time through personal study and through correspondence courses. This book

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by no means delimits the boundaries of your learning. The next section indicates possible study material sources that you should investigate once you are on board ship and in a position to take advantage of them. You can obtain details on correspondence courses through your education officer. Most of the books that you will find it profitable to study will be available aboard ship; the others can easily be obtained through routine channels. These study sources will help you both in training for current assignments and in preparation for future work of more scope and responsibility.

You will find special educational value in ship and fleet exercises and drills. You will get more out of such exercises if you prepare for them by studying the appropriate doctrinal publications in advance, and if you participate in the technical preparations your fellow officers and leading petty officers make for them.

1E4. OCS STUDENTS

Except for article 1E3, the preceding articles in this section apply specifically to NROTC students. During your intensive training period, you as an OCS student will be more or less limited to this textbook and other study materials on ordnance and gunnery that are furnished by the school. If you have as a college undergraduate studied courses like those mentioned in article 1E2, you will find this background a worthwhile advantage.

The suggestions on active duty training in article 1E3 will apply to you as an OCS graduate as much as they apply to all other naval officers—and you have probably learned by now that a conscientious naval officer's professional education continues all through his career.

F. Published Sources of Information

1F1. TYPES OF PUBLICATIONS

The competence of a naval officer depends not only on what he knows, but also on his ability to find quickly a reliable, authoritative source for other information he needs. For this he must depend on and be well acquainted with published sources of information.

The principal types of Navy publications which you as a naval officer aboard ship will use in connection with ordnance and gunnery include technical, tactical, and training publications.

1F2. TECHNICAL PUBLICATIONS

Most of the technical publications the weapons officer is concerned with are issued by the Bureau of Naval Weapons. Other technical publications are handled by the Bureau of Supplies and Accounts (BuSandA). BuSandA operates a Forms and Publications Supply Office at Byron, Ga. The available publications are indexed in NavSandA Publication 2002, Cognizance Symbol I.

Ordnance Pamphlets (OPs) are of two types. Most OPs are of the first type, in which each OP serves as a technical manual on a specific ordnance equipment, including a description of the equipment, its operation, maintenance, installation, and repair. Relatively few OPs are of the second type, in which the OP is a treatise on some ordnance subject such as battery alignment or ammunition. All OPs (unclassified or confidential) as well as a number of other types of BuWeps technical publications, are indexed in OP 0. OPs are numbered consecutively without any attempt of coding. Ordnance technical publications of higher security classification are indexed in RPS 6.

Ordnance Data (ODs) are used for publishing a variety of technical information, including test and inspection information, advance information or instructions on ordnance equipment, ordnance equipment lists for specific types of ships, and the like. ODs are numbered serially and are indexed in OP 0.

Ordnance Alterations (OrdAlts) prescribe specific authorized changes (as distinguished from repair and other maintenance work that does not alter the design or characteristics of the equipment) in specific ordnance equipment. Alterations of ordnance equipment are permitted only as authorized by OrdAlts, and they must be made strictly in accordance with the drawings and instructions that form part of the OrdAlts. When they are completed they must be recorded

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in the maintenance records of the gunnery department and reported to BuWeps. OrdAlts are listed in a special index published as OrdAlt 00.

Ordnance Instructions and Ordnance Notices are BuWeps-issued directives published in accordance with a decimal number scheme prescribed by the Office of the Secretary of the Navy. This scheme provides for subject classification and numbering of issues relating to administration, supply, procurement, production, fiscal matters, and the like. BuWeps directives are indexed in NavWeps Note 5215.

Ordnance Allowance Lists (NavOrd Lists) are looseleaf lists of required equipment, ammunition, tools, accessories, etc., for an ordnance installation. Revisions or amendments are made by issuing new pages which are substituted for old ones. There are two indexes of NavOrd Lists—NavOrd List 00 (double zero) and NavOrd List 0 (zero). The first of these shows for each ship the NavOrd Lists required to make up a complete set for that ship. The second, NavOrd List 0, specifies for each NavOrd List the pages that should be in it to make it up to date. Don't confuse Ordnance Allowance Lists (NavOrd Lists) with Ordnance Equipment Lists. The latter are issued as ODs, apply to classes or groups of ships, and are intended primarily to guide shipyards and shipbuilders. NavOrd Lists, on the other hand, are effective while the ship is in commission, and serve as the authority for issue of ordnance material to ships that have not been converted to bin storage in central storerooms.

ORDNANCE SEGMENT OF COSAL is the authority for issue of ordnance material to those ships which have been converted to central storerooms. COSAL stands for COordinated Shipboard Allowance List and includes the spare part items for all departments on the ship. Issue and inventory are controlled by supply department personnel for all shipboard departments, and this centralized control saves space, material, and man-hours. COSAL is tailored to meet the needs of an individual ship, and is prepared in segments by category of material in simplified and uniform format.

BuWeps Bulletins are classified quarterly periodicals containing articles on new developments in naval ordnance, equipment in the fleet or under development, new safety information, newly developed modifications to ordnance gear, and other timely information. They also list new publications issued since the latest issue of OP 0.

There are many other publications issued by the Bureau of Naval Weapons, but these represent the minimum that you should know about in preparation for a shipboard assignment.

Weapons department personnel use and may maintain a considerable amount of equipment under BuShips cognizance, such as dredger hoists, compass repeaters, sonar gear, speed indicators, and wind data receivers. Technical manuals for such equipment are published by BuShips and furnished to weapons department personnel.

Weapons department personnel also maintain all or part of such systems as high-pressure air distribution systems and sprinkler systems. For technical information on these systems, see the appropriate drawings (ship's plans), your ship's Damage Control Book and General Information Book, and the BuShips Technical Manual. The BuShips manual consists of a number of separate chapters, each bound like an independent pamphlet, and each on some aspect of the ship's structure or plant.

1F3. TACTICAL PUBLICATIONS

The Chief of Naval Operations (CNO) issues several series of publications intended to present doctrines and procedures for the use of U.S. Navy ships, aircraft, and weapons in combat. In naval warfare usage, a doctrine may be defined as a working principle or rule of combat that has been developed theoretically and proved by experience. Procedures are methods used to put the doctrine into effect. These publications are concerned also with team combat training—the training of groups in fighting units, as distinct from individual training mentioned later on in this chapter. All these doctrinal publications are classified.

The primary series of doctrinal publications issued by CNO is the Naval Warfare Publications (NWPs). There are four groups of these. Group I takes up basic principles and planning, groups II and III are devoted respectively to naval operations and the procedures they require, and group IV deals with specific fleet exercises. The group I doctrinal publications also include, besides NWPs, several Allied Tactical Publications (ATPs) and Allied Communications Publications (ACPs); these apply in the U.S. Fleet as designated by CNO. The group IV publications are identified either as Fleet Exercise Publications (FXPs) or Allied Exercise Publications (AXPs), not as NWPs.

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Supplementing the primary doctrinal publications mentioned above are the Naval Warfare Information Publications (NWIPs) and several ATPs and FXPs. These expand in detail certain aspects of primary publication content. The entire doctrinal publications system is described in NWP 0, which contains charts explaining in detail the interrelationships among the publications mentioned above, and has detailed indexes of their contents.

In your duties aboard ship as an officer in the weapons department, you will find that the doctrinal publications most useful to you at the outset will be:

1. The publications directly concerned with the type of ship you are on, its mission, and often your assignment in your department. For example, if the DD you are in is preparing for amphibious operations and you are assigned as weapons liaison officer in CIC, you should be studying NWP 22, NWIPs 22-2 and 22-7A, NWP 31A, ATP 4, and appropriate parts of FXPs 3A. These have to do with amphibious operations, CIC operations, naval gunfire support, and fleet exercises (including amphibious).

2. ATP 1A. Vol. I. The information here is essential to any officer assigned as watch officer, JOOD, or OOD, particularly when underway.

3. NWP 10A, a basic publication on the principles of sea power and the U.S. Navy's mission. In some commands this is more than recommended reading; it is required.

4. NWP 50A. The student should concentrate on those parts of this book that deal with weapons department organization and operation, and the relationship of the weapons department to other shipboard departments.

1F4. TRAINING PUBLICATIONS

The Bureau of Naval Personnel (BuPers) is charged with all training of naval personnel other than group combat training (which is under CNO). BuPers therefore issues all text material specifically designed for training purposes and intended for Navy-wide distribution. The book you are now studying is a BuPers publication of this type. The training materials published by BuPers fall into the following categories:

1. Navy training courses for enlisted personnel. Most of these are intended for enlisted personnel to study in preparation for advancement to specific ratings and grades, but some are courses in common subjects such as electricity and mathematics.

2. Navy courses for officer personnel. These cover subjects of specific interest to officers, such as this book and The Weapons Officer, NavPers 10867A.

3. Correspondence courses on specific subjects. These are designated as enlisted or officer courses. The courses are based respectively on the texts of the two types mentioned above. Officer courses are available to personnel on active duty or in the reserves. They are administered by the U.S. Naval Correspondence Center, Scotia, New York.

4. Special-purpose publications that do not fall into the categories above, such as the periodically issued List of Training Manuals and Correspondence Courses, NavPers 10061 (followed by a letter indicating the revision). NavPers 10061 serves as a catalog of NavPers publications.

Aboard ship, the officer newly assigned to the weapons department will probably find most useful a copy of the books in the present course, plus The Weapons Officer, NavPers 10867A, and such others as will be applicable to his assigned duties. NavPers 10061 is a good reference to investigate for this purpose.

G. Safety Precautions

1G1. SAFETY PRECAUTIONS

A universal objective of all U.S. naval training programs for all personnel is safety. Active attention to safety is a part of all courses taught in Navy schools, and all training publications are concerned with it as well as with their principal subject matter. All supervisory personnel, enlisted and commissioned, are concerned with safety.

Since safety is so all-pervading a subject, it is obviously impractical to try to divorce it

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entirely, for study purposes, from the activities and operations with which it is connected. To indicate the type of safety considerations that the Navy deems important in connection with ordnance, an extract from the Navy publication U.S. Navy Safety Precautions is reprinted as an appendix to this book. However, the weapons department officer aboard ship should be aware of other primary sources of safety information available to weapons department personnel. They are listed here for reference purposes.

1. Technical publications issued by BuShips; and BuWeps on equipment under their cognizance contain safety information as required in connection with proper operation, maintenance, and adjustment of the equipment.

2. BuWeps also issues OPs on certain aspects of safety, as follows:

a. OP 4, Ammunition Afloat, and OP 5, Ammunition Ashore.

b. OP 1014, Ordnance Safety Precautions, Their Origin and Necessity.

c. OP 1591, Clearing of Live Ammunition From Guns.

3. BuPers issues the following publications containing safety information:

a. The Weapons Officer, NavPers 10867A.

b. Navy training courses (including basic courses) contain safety information in appropriate contexts.

4. Other sources.

a. Safety placards and cautionary nameplates appear on equipment and in its vicinity where considered advisable for the warning of operating and maintenance personnel.

b. Army technical publications, used in the Navy particularly for small arms, have considerable safety information as it concerns small arms and ammunition.

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CHAPTER 2

SHIPBOARD WEAPON SYSTEMS

A. Evolution of Naval Weapons

2A1. INTRODUCTION

In your naval orientation course you studied the influence of seapower on world history, tracing it as far back as the wars in ancient times between the Greeks and the Persians. You learned how Roman seapower turned the Mediterranean into what the Romans called "Mare Nostrum" (our sea), so that the invading Carthaginians had to go hundreds of miles overland to bypass Roman seapower. You learned how, following Columbus' voyages, seapower made Spain's access to the New World the root of her imperial power, and how later on a single major victory at sea transferred to Britain the power that the Spanish lost. You learned also how important seapower (particularly of France, Holland, and Spain) was in helping us win our independence. You may not have learned in the orientation course that British and American seapower stood behind and "covered" the Monroe Doctrine that kept European colonizers largely out of the Western Hemisphere in the 19th century, but it did. Examples of the influence of seapower on history could be multiplied. Instead, consider briefly now how evolving armament and the technique of using it have affected seapower in the past, and a few dominant trends in the future.

2A2. GUNS AND OTHER WEAPONS EFFECTIVE AT A DISTANCE

Warships in classical and early medieval times engaged each other effectively by ramming or by grappling and boarding for hand-to-hand combat. Until the development of the naval gun, this remained the classical pattern, although crossbows, incendiary pyrotechnics ("Greek fire"), and shipborne spring- or torsion-powered artillery did allow some battle action before actual ship-to-ship contact. As guns developed, ranges increased from 80 to 300 feet for early naval cannon to 40,000 yards and up for the World War II battleship. Most of this increase took place relatively recently; in our Civil War a mile was rather far for accurate gunnery, and even in the Russo-Japanese War (1905) the opening range was only about 6,000 yards. Aircraft and guided missiles have even more radically increased battle ranges, as indicated below.

The most novel results of the increasing range of seaborne weapons have been to increase the importance of naval firepower in land warfare, to increase its potency as compared with landbased firepower, and to increase the importance of amphibious warfare. Modern naval gunfire and aircraft can range many miles inland to attack specific objectives, to support land forces (as supplements to land artillery), and to support amphibious landings. Compare, for example, the successful Inchon beachhead (Korean War) with the Gallipoli fiasco (World War I). The increase in range has increased the distance between combatant forces in purely naval engagements also, and it has had a number of other side effects.

The extreme in this trend toward increasing separation between attacker and target has recently been attained by missiles which can span whole oceans to reach their targets.

2A3. EXPLOSIVES

The development of nuclear fission, and then fusion, revolutionized not only weapons but even the art of war, to say nothing of its effects, still not entirely known, on mankind in general. But explosives (as distinct from specific explosive weapons) have been revolutionized before—first

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with the discovery of gunpowder, then the invention of guncotton and its nitro-based successors, followed by the development of powerful but insensitive explosives, and the continuing improvements in gun propellants and in the latest chemical explosives.

One effect of the increased lethal range of explosive weapons resulting from the use of the new explosives, particularly nuclear, has been to increase the dispersion required to minimize combat damage to ships in convoy and combat groups. Coupled with the improvement of aircraft, undersea craft, and missiles, another effect has been to force the development of picket vessels and of early-warning systems that were not even conceived as recently as 1940.

2A4. FUZES AND RELATED DEVICES

Projectiles designed to explode on impact were used soon after cannon were developed. However, they were quite unreliable and unsafe. They were the "bombs bursting (prematurely) in air" that Francis Scott Key saw; they did relatively little damage, and did not become really practical until around the middle of the 19th century when adequate fuzes were first developed. Fuzes have since become more and more subtle and refined, from simple impact types through mechanical time fuzes and modern proximity fuzes. These last in a general sense include not only projectile fuzes that operate by radio transmission, but also the equally sophisticated underwater weapon devices—acoustic, magnetic, and pressure-sensitive—which are used in mines, torpedoes, and depth charges.

The result of all these developments has been to increase the destructive efficiency of the weapons and projectiles in which they are used, in that the weapon or projectile will function effectively without actual physical contact with the target. The consequent increase in antiaircraft weapon effectiveness has to some degree offset the development of higher performance aircraft. Underwater, the effect has been to increase the complexities of defense and attack, as well as the dangers of both surface and undersea targets. Probably the most spectacular corollary of the development of sensitive underwater devices has been the concurrent development of the torpedo that can seek out its target after a run in its general direction. This, along with the snorkel, nuclear power, and hydrodynamic developments (e.g., the shape of the Albacore), has had a revolutionary influence in changing submarine and antisubmarine warfare from what it was early in World War II.

2A5. UNDERWATER WEAPONS

Underwater weapons include the mine, the torpedo, and the depth charge.

The mine is a weapon effective at a distance in time as well as space. After it is planted, it waits until a ship comes close enough to set it off. Mines are a means of controlling the sea by denying ships passage through it, or making such passage excessively hazardous. An example of the effectiveness of mines in such as application during the Korean War was the enemy's mining of the Wonsan area, a relatively favorable landing site. This prevented the United Nations forces from making a second beachhead there, and impaired the effectiveness of the campaign to roll back the North Korean-Red Chinese forces.

The automotive (self-propelled) torpedo, an unmanned explosive-laden submarine, was first developed in practical form in the 1870s. Early in the 20th century it was considered so potent (particularly in the days of metal ships lacking modern compartmentation) that special torpedo-boats were used to launch them. A specialized craft to counter the torpedo-boat was developed—the torpedo-boat destroyer, which has evolved into the modern DD. The torpedo is now the most advanced weapon used against submarines, as well as the chief weapon used by submarines.

Unlike mines and torpedoes, which can be used against either surface or submarine targets, the surface-launched depth charge (when dropped from aircraft, called the depth bomb) is specifically an antisubmarine (A/S) device. When first developed in World War I, and until the midst of World War II, large depth charges were either dropped astern or heaved a few score yards over the side by a small propelling charge in a special gun, and were detonated by a hydrostatic device when they reached a set depth. Currently used designs, called thrown weapons, are much smaller, may be propelled either by a rocket or a mortar device, and are either contact- or proximity-fuzed, but their most important characteristic is that they can be fired at much greater ranges (up to several hundred yards). This has led to a change in antisubmarine tactics; A/S vessels are no

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longer forced to stay close to the target submarine, crossing and recrossing its presumed location. Using the crossing technique frequently caused the DD to lose sonar contact in its own screw noises. Using thrown weapons that are thrown ahead of the DD's track (ahead thrown weapons) eliminates this difficulty. Newer depth charge weapons which extend the aerial flight time are discussed in chapter 10.

2A6. FIRE CONTROL

The improvements in gun ranges mentioned earlier in this section could make guns effective only if the guns were adequately controlled so that their projectiles would hit the target. The evolution of gun fire control begins in the 19th century with the invention of fixed sights, and continues with the development of movable sights (something like those on modern military rifles) in the 1840's, telescopic sights and drift-and windage-compensating sights (1850's and 1860's), fire control directors and optical range-finders (World War I), and fire control computers and plotting techniques (after World War I).

The most spectaular World War II fire control innovation was radar, which made accurate fire control possible even when optical instruments were useless. Radar has been mainly responsible for the enormous accent on electronics characteristic of the fleet today. A prewar DD had, for example, perhaps 100 vacuum tubes all told; a modern DD has in the neighborhood of 4,000.

Parallel with the development of radar came the development of sonar. Even as early as World War I, hydrophones were used both by destroyers and submarines to listen for underwater and surface targets. The development of active ("ping") sonar revolutionized underwater detection by making possible the detection of passive targets (i.e., those that do not radiate noise). But though the principle of sonar resembles that of radar, its range and accuracy are not on the same order, and in its present state of development, though it is constantly under improvement, sonar has serious limitations which prevent the most effective use of underwater weapons. Moreover, present trends indicate that in the future effective A/S warfare will be much more important than it ever has been in the past. At the same time, sonar and other listening equipment of current types is (other things being equal) likely to be significantly more efficient in submarines than when located in surface vessels. There are factors that favor surface operations, but it is clear that the submarine hunter on the surface has a difficult job.

2A7. CONCLUSION TO HISTORICAL DISCUSSION

The preceding paragraphs have indicated in broad outline some of the effects of developments in important naval weapons, but much has been omitted (guided missiles and rockets for example); and the development of the vehicles themselves (surface ships, submarines, aircraft, propulsion and navigation equipment, etc.) has not been covered. Some of the present trends in weaponry are indicated later in this chapter.

B. The Weapon System Concept

2B1. EMPLOYMENT OF WEAPONS

The effective use of any naval weapon requires that a destructive (generally explosive) device be delivered to (usually) a moving target; the accuracy with which the location and velocity of the target are known is vital to the success of the attack. We have noted above the increase in target velocity and range, characteristic of modern operations. The result has been that today, for effective use of a weapon, it must be considered and employed not individually but as part of a weapon system.

2B2. ELEMENTS OF A WEAPON SYSTEM

The phrase "weapon system" was defined in general terms in the preceding chapter. We can now be more specific. A weapon system, taken as a whole, must include:

1. Units which detect, locate, and identify the target.

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2. Units which deliver or initiate delivery of the destructive device of the weapon to the target. (The term "weapon" is used flexibly in different contexts; for example, a gun is a weapon which delivers a projectile to the target, while a mine is a weapon that itself explodes when a target activates it.)

3. Units that control a delivery unit or weapon to direct its delivery; that set the fuze (or equivalent) of the destructive device; or (as with a torpedo) that "program" or preset a target-seeking device as required for maximum effectiveness in reaching the target.

4. Destructive units (usually termed "weapons") which will destroy the target when in contest with it or when in its vicinity.

The sections following this one will take up each of these types of component units in somewhat more detail.

2B3. WEAPON SYSTEM REQUIREMENTS AND EVALUATION

The Navy has evolved a rather elaborate series of stages through which any weapon or associated item must go from the time it is a gleam in some engineer's or Navy man's eye until the solid hardware itself is installed for service use aboard ship. Although the fundamental idea on which the item is based may originate almost anywhere (ideas are welcome regardless of the source), it is the Chief of Naval Operations, speaking for the ultimate user, the fleet, who sets the requirements that the weapon or whatever it is must meet. The prototype (first installed model) of any instrument or piece of equipment which bears a Navy nameplate that you see on a naval vessel has been through exhaustive engineering and shipboard application tests, and meets the fleet's requirements for what that specific item must do, and how well it must do it.

The trend in recent times has been increasingly toward design and procurement of complete weapon systems, rather than of component units which later evolve into a system. This is especially true of newer systems such as missiles with their complex guidance and propulsion systems, as contrasted with most systems based on guns, which were not originally conceived as systems but evolved that way.

The statement of requirements for any weapon system or component unit can be considered as responses to two questions—

1. What is the (system or component unit) supposed to do?

2. How well is the (system or component unit) supposed to do it?

The answer to the "what" question is often called the "military requirements." It is a statement of the nature of the equipment (whether it's a gun, a torpedo, a radar, a computer, etc.) and its capabilities or what it can do (if a gun, its range, rate of fire, etc.; if a torpedo, its speed, range, accuracy, etc.; if a radar, its range, accuracy, sensitivity, etc.; if a computer, its speed, accuracy of solution, limits of operation, etc.). Obviously, all this is entirely dependent on the nature of the system or component unit. Moreover, in a system, each component's requirements depend on the characteristics of the other components and on the requirements of the system as a whole. Thus, the capabilities of any system are limited by those of the "weakest link" in the system. (For example, a computer in an A/S system can solve fire control problems beyond the ranges possible to the sonar equipment in the system; the sonar's range therefore establishes the system's range.)

Aside from what we have here called the military requirements which depend on the nature and task assigned to weapon systems and weapon system components, there are general requirements that are pretty generally applicable to all, regardless of the nature of the system or component. These can be considered as the answer to No. 2 above. We can state them here only in qualitative terms, since this is a general discussion; in system specifications these requirements are reduced to specific values:

1. RELIABILITY. The system must be capable of continuous long-period functioning under specified adverse conditions at specific rates (e.g., rounds per minute fired, or hits maintained at specified accuracy, etc.).

2. FLEXIBILITY. The system must be capable of functioning satisfactorily in spite of failures in quality of power supply, ammunition, etc.; it may also be required to function satisfactorily with certain components omitted or disabled, or with others substituted.

3. SAFETY. The system must be perhaps not foolproof, but hazardous conditions must be eliminated by interlocks or other means; it must not endanger friendly ships and aircraft or ownship structure or personnel.

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4. SIMPLICITY OF OPERATION. Complex modern weapon systems cannot be made inherently simple, but they should be designed for operation by personnel with the characteristics of human beings. These considerations influence design of control arrangements, provisions for safety and comfort of operating personnel, and functional design to make the equipment as simple to operate as its nature will permit.

5. MAINTAINABILITY. This requires not only design using long-life components, but also convenient (and in many cases almost entirely automatic) testing and trouble-diagnosing gear that is either part of or is easily connected to the equipment. Moreover, this requirement has led to the development of the unit replacement principle—thus, if an amplifier, for example, burns out, the procedure is not to test each component in it and make repairs as necessary, but to pull out the whole amplifier (which is a complete plug-in unit) and plug in a replacement. The defective unit can then be repaired later and put back in stock as a spare.

Note that in weapon component or system design these requirements often conflict with each other. For example, a fuzing system may be made so safe that it won't function reliably. Much of the work in weapon design is concerned with attaining practical compromises between conflicting requirements.

The evaluation of a weapon system or component unit can be defined as the study of the system or unit, measurement of its effects, and appraisal of its effectiveness. As in development of ordnance material, the trend is toward evaluation of complete systems rather than independent units; in system testing and evaluation, however, component units are tested individually as well as with relation to their systems. Before a system or component is accepted for fleet use, it must go through both TECHNICAL (i.e., engineering) and TACTICAL evaluation, following standard prescribed procedures.

2B4. COORDINATION AND DISPERSION IN WEAPON SYSTEM EMPLOYMENT

Concurrently with the increasing complexity of weapons and weapon systems, naval operations have become more complex. Modern naval engagements involve targets in the air, on the sea surface, and below the sea surface; the variety of weapons is growing; the speed and maneuverability of targets is increasing; and there are novel operations like long-range shore bombardment, amphibious landings, antiaircraft (AA) and A/S attacks, screening, and radar picket duty (to take a few examples), the like of which did not exist until recently. The contrast is of course most clear when you compare naval warfare of 50 or 100 years ago with today's, but it is evident even when you compare World War II operations with today's. When you take note of this trend, the increasing importance of coordination among all participating elements in an operation becomes obvious. Since the aircraft, ships, and submarines participating in an operation can be considered primarily as weapon systems vehicles, it is equally obvious that the requirement for coordination is particularly applicable to the weapon systems concerned.

As the ranges and explosive effect areas of modern weapons have increased, they have dictated increased dispersion of formations of naval ships. Convoys and task groups arranged according to present day doctrine have ships much more widely spaced than was the practice even as recently as World War II. An attributable factor is the development of atomic weapons, which add to the blast and fragmentation effects of former conventional weapons, (but, of course, on a much magnified scale) the threat of radioactive contamination. Another factor which makes wider dispersion necessary is the increased speeds of aircraft and missiles which may attack the formation. More dispersion is needed, in the direction of the threat, so that outer perimeter units may give early warning of an attack.

The effects of this dispersion requirement are to increase the difficulties of coordination, and to increase the requirement for improved long-range underwater target detection performance.

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C. Detecting Devices

2C1. FUNCTIONS OF DETECTING DEVICES

The first steps in the functioning of a weapon system are the detection, location, and identification of the target. Ideally, the device performing these functions should detect the target at maximum range, and establish the target's location, orientation, and velocity with respect to own ship, with maximum accuracy and minimum delay. At the same time this device should identify the target both as to exactly what it is and whether it is enemy or friendly. And, ideally, the device performing these functions should be equally efficient regardless of which medium it operates in, regardless of the conditions in that medium, and regardless of interference originating with the enemy, with friendly forces, or with natural causes.

No detecting (for the present let this term include locating and identifying) device or system yet developed measures up without possibility of improvement to any of these ideals. The ideals are useful chiefly as standards by which the effectiveness of detecting devices can be judged. The principal detecting devices now used in the fleet include

optical devices
radar
ECM (electronic countermeasures)
sonar
MAD (magnetic airborne detection)

All except the last of these depend on detection of radiation—the first three on electromagnetic radiation, the fourth on sound radiation. MAD depends on detecting differences in magnetic fields.

Optical devices are invariably passive, i.e., they detect radiation emitted or reflected by the target, but don't produce the radiation they detect.

ECM equipment falls into the passive category when used for detection. But ECM gear also has an active mode for use in jamming the enemy's electronic detection equipment. Sonar may be either passive or active when detecting subsurface targets. Its active device produces radiation which it detects as a reflection from the target. Radar can only be active.

2C2. OPTICAL DEVICES

Optical devices in weapon systems always function to establish target bearing and (for air targets) target elevation. Some optical devices can measure the range to the target. Except for highly unusual atmospheric conditions, in which light rays reflected from the target to own ship are perceptibly bent by refraction, the line of sight (a straight line from target to observer) is truly straight. Optical devices which incorporate lens systems are designed to magnify the image of the target; this extends the capabilities of the human eye in target detection and identification.

Since optical devices depend on visible light reflected from the target, they are handicapped by darkness (unless the target is luminous), fog, and visible obstacles. Optical devices are always passive (i.e., they never provide the light that makes the target visible), but an attacking ship can illuminate a target by firing gun projectiles which release parachute-supported flares in the vicinity of the target, or by using aircraft to drop such flares.

At the present time, no optical detecting devices for shipboard use depend on light radiation invisible to the unaided eye (such as infrared light), although land forces have such devices for use at close range.

Since light in general travels in straight lines, a target cannot be optically detected if it is entirely below the horizon (like target No. 2 in figure 2C1).

2C3. RADAR

In our short discussion of radar we will concentrate on its ability to measure the range or distance to a target. Navy radars can measure the target's angle of elevation above

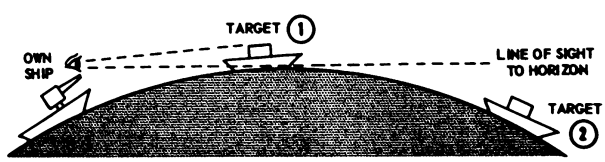

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Figure 2C1.—Limits of optical detection.

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the surface horizontal, his altitude, and his true or relative bearing. This is, of course, if they are designed to do so. The target's speed can also be quickly determined if we add some minor computing units. In chapter 6 you will learn more about how radar works, but for now let's find out how it measures range.

Every naval ship is equipped with a powerful sound producer—its whistle. Suppose that the whistle on your own ship sounds a short, sharp blast while it is a mile or two distant from another ship. If you listen carefully after the blast sounds, you will hear an echo reflected from the other ship. If you know the speed of sound, and can measure accurately with a stopwatch the time elapsed between the whistle blast and the echo, you can easily determine the range to the other ship. This is a simple application of the distance, rate, and time equation which you learned years ago. You'll notice one slight variation however; the product of rate and time must be divided in half to account for the two-way travel of the sound wave.

If instead of a sound producer you use a powerful radio transmitter, and instead of your ears you use a radio receiver, you have the essentials of radar. (The name "radar" comes from RAdio Detection And Ranging.) Figure 2C2 shows one transmitted pulse and one reflected echo as they travel between our own ship and the target. Notice that the transmitted pulse covers a larger area in space as it gets farther away from own ship. The amount of this increase depends on many variables, one of which is the type of transmitting antenna used. Notice also that the reflected echo is smaller in amplitude since only a portion of the transmitted energy is reflected by the target. Further, the echo expands as it approaches own ship and only a portion is actually received by the receiver. To be of any use the reflected echo must be greatly amplified in the radar receiver before it can be displayed on the cathode-ray tube. The cathode-ray tube (something like a TV picture tube) provides a visible display which can indicate target range, bearing, or elevation. The display in figure 2C3 is designed to provide range information only, and it could be the results of the situation in figure 2C2. The vertical "pip" or "blip" at the left of the sweep trace in figure 2C3 represents the transmitted pulse; the center pip is the target echo. The sawtooth like shape at the right of the display is the range measuring device, which is called the "range step" in this case. You will see in a moment how the range step is moved to the echo to measure range, but first let's learn a little more about the sweep trace.

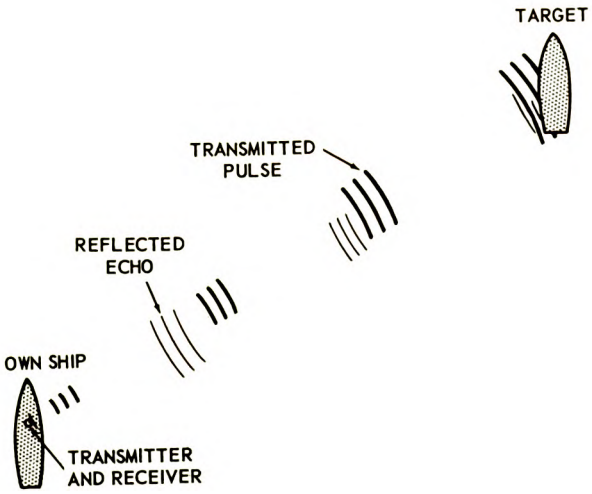

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Figure 2C2.—Principle of radar.

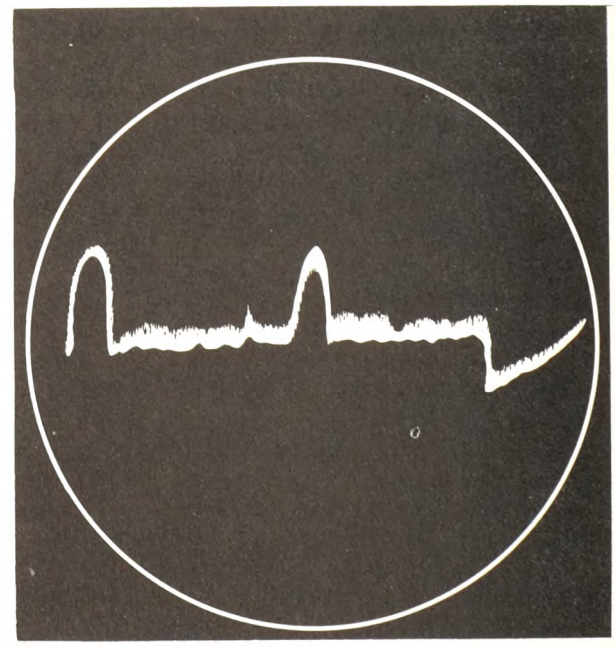

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Figure 2C3.—A common type of radar display.

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Even though the display appears to be continuously illuminated, it is in fact caused by a pencil-point beam of electrons which are made to "sweep" across the face of the scope from left to right. The sweep frequency is the same as the pulse repetition frequency of the radar. In layman language this simply means that every time a transmitted pulse leaves the antenna, a sweep is started. Actually, the sweep starts just a little earlier so the transmitted pulse can be viewed. The apparently continuous picture is the result of a property of the scope face called persistency, which means that a given point on the scope face continues to give off light for a short time after the beam of electrons has passed it. You have seen this effect before when you turned off a TV set and watched the illumination slowly fade.

The transmitted pulse, echo, and range step are shaped by bending the beam of electrons above and below the vertical center of the scope, which is the normal vertical position of the sweep trace. Vertical deflecting plates or vertical deflecting coils are used for this purpose. In our example, the transmitted pulse must have been applied to the vertical deflecting plates before the reflected echo, and the echo was applied before the range step. This is how the stopwatch is replaced. The designers simply arrange the scope so that a given portion of the sweep trace equals a certain number of yards (in some cases, miles). Then we can measure the trace distance, which is based on time, between the transmitted pulse and the echo. The sweep is made to move from left to right on the scope by horizontal deflecting plates or coils. The sweep movement is linear. It is based on time, and it is accurately matched to the range measuring circuitry.

In the preceeding paragraph we mentioned "based on time"; let's explore this a bit further. The speed at which radar energy travels is 186,000 miles per second or 300,000,000 meters per second—the speed of light. Because of this great speed, the time elapsed between transmitting and then receiving an echo is measured in microseconds (millionths of a second, or μsecs). Obviously, a stopwatch will not do the job. As you have seen, a cathode-ray tube is used instead. With the speed of light as the reference, we find that radar energy travels 328 yards in 1 μsec. From this we can say that 1 nautical mile (about 2,000 yards) will be traversed by the energy in 6.1 μsecs. This is the time standard upon which most radars, and certainly most fire control radars, have been designed. Once again, it takes 6.1 μ secs for the energy to travel 2,000 yards, these 6.1 μsecs are equal to 1,000 yards of RADAR RANGE.

Now let's measure the range to the target in figure 2C3. A range counter is attached by mechanical linkage to a range handcrank, or to a range drive motor which drives the mechanical linkage. Moving the mechanical linkage by either method moves the counter and positions the range step to the corresponding position on the sweep. All the operator has to do to measure range is position the range step under the target echo and read the range from the counter. Moving the range linkage changes the time relationship between the transmitted pulse and the range step, and therefore controls the horizontal position of the range step on the sweep. If the range step were under the transmitted pulse, the range counter would read approximately zero yards. It would increase as the range step moves from left to right across the sweep in response to the operator's input.

Radar transmission is made from a metal structure called an antenna. Unlike the sound from a ship's whistle, which radiates almost equally in all directions, most of the energy in a radar pulse is directed along the bearing on which the antenna is pointed at the instant of transmission. The same antenna also picks up the echo. To get 360° coverage, radar antennas rotate continuously; antennas on radars designed to concentrate on a narrow angular sector are instead aimed by an operator. In addition, many of the latter type also oscillate or nutate through a small angle.

Radar signals are conducted to and from the antenna by special tubular waveguides that look something like ordinary air or water piping. Some use coaxial cables.

Radar shares many of the characteristics of optical detecting devices. Except for certain atmospheric conditions which to a minor extent distort the paths of the transmitted and reflected pulses, they travel in straight lines. As compared with a sound-ranging system like the one mentioned briefly by way of example at the beginning of this article, radar has much more range, functions several thousand times more quickly and much more accurately, and is not affected by audible noise. It is quite accurate (to within a degree) in measuring target bearing and elevation, though not quite as accurate as optical devices. It is the most accurate and

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the longest in range of our range-measurement devices. It is not severely affected by adverse weather and fog, is just as usable at night as in the daytime, and is virtually immune to static and electromagnetic disturbances that plague communications radio and TV. And its signals can be used to guide missiles, or to guide target-tracking equipment.

But radar has disadvantages too. It can be jammed or interfered with by enemy radar transmissions and other countermeasures. It does not permit of easy identification by target silhouette or other visible characteristics; it shows only a blip for a target, and may show but one blip for several targets. As compared with optical methods, it requires skills in interpretation of its displays amounting almost to an art. Its complex electronic circuitry, waveguide plumbing, and mechanical rotating and nutating gear require constant attention to maintenance. As is true of any revolutionary technical advance that every one has come to depend on heavily, its loss through malfunction or battle damage is an especially severe handicap. Lastly, radar pulses can be detected by the enemy at much greater ranges than those at which the pulses will reveal to the originating ship the enemy's presence. As the discussion later of ECM will indicate, radar pulses are a telltale that may reveal a great deal of other information to the enemy also.

In spite of these disadvantages, radar is the primary means of detection used in the fleet today.

2C4. ECM

ECM (Electronic CounterMeasures) have been defined as the means by which your own forces attempt to nullify advantages of enemy electronic devices, and to obtain all possible information concerning enemy electromagnetic radiations. ECM may be either passive or active.

Passive ECM are measures not detectable by the enemy. The most important is intercept search, by sensitive receiving equipment, of all electromagnetic wavelengths that the enemy might use, detection of electromagnetic radiations, and determination of their source and characteristics. Intercept search will detect radiation from any kind of electronic equipment—radars, radios, electronically controlled weapons, and electronic navigational aids. It will show the direction from which the radiation is coming, and display and record the radiation so that it can be analyzed. From such analysis can be determined such information as the type of equipment radiating, what its function may be, and the number of transmitters involved. You can think of ECM almost as a kind of passive radar.

Other passive ECM methods are tactical evasion (to avoid detection by the enemy) and control of electromagnetic radiation by own ship (i.e., silence imposed on own-ship electronic transmitters) to avoid telltale radiation detectable by enemy ECM.

Active ECM includes those methods which the enemy can detect. In fact, its purpose is to impair the operation of the enemy's electronic devices (such as radar) by feeding them false signals. One method is jamming—radiating interfering or deceptive signals by electronic transmitters. The other is deception—using mechanical reflecting material to mislead his radars.

ECM does not have as important a role in weapon systems as optical devices, radar, and sonar do. Weapon systems can incorporate active ECM; there are gun and rocket projectiles designed to scatter radar-reflective material. Passive ECM may be used for direct guidance of weapon systems. The commonest present naval application of passive ECM is the use of intercept search in preliminary guidance of weapon system detecting equipment, and other passive ECM methods are used to prevent enemy interference with weapon system functioning.

2C5. SONAR

Radar cannot be used under water, because water absorbs radio waves. But water does conduct sound—better than air does, in fact. And sound is what the Navy uses to detect underwater targets.

It is possible to detect a submarine operating under power by merely listening—with the aid of a suitable microphone. But present-day submarine detection equipment more often functions somewhat like radar—it emits a pulse of sound energy, then picks up echoes. The equipment is called SONAR—SOund NAvigation and Ranging—and it not only detects underwater targets, but also locates them in terms of range, bearing, and depth.

The main units of the sonar equipment (Fig. 2C4) are a transducer housed in a water-filled dome (a streamlined housing protruding from the ship's hull) and STACK, manned by a

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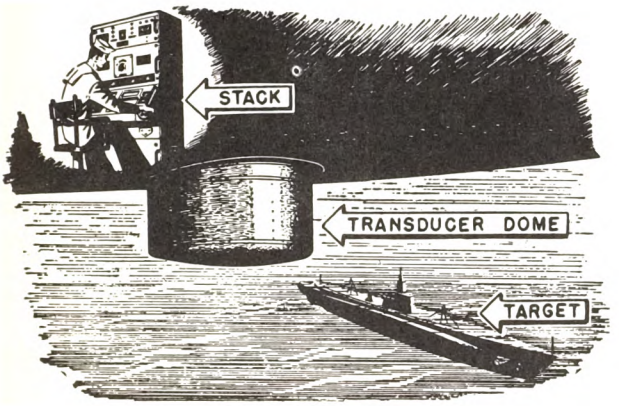

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Figure 2C4.—Elements of sonar system.

Sonarman. The stack periodically produces a powerful pulse of alternating current, which is transmitted to the transducer. The transducer converts the current into a pulse of high-frequency sound (around 20,000 cycles per second), and projects it into the water. The transducer then switches to receive echoes, which are amplified in the stack. However, sound vibrations of 20,000 cycles per second are ULTRASONIC—too high in pitch to be audible to people of normal hearing. So the stack's electronic circuits convert the echo to an easily audible 800 cycles-per-second note, which the Sonarman hears over the stack's loudspeaker. A visual indicator presents an image of sonar echoes as blips on the face of a cathode-ray tube (much as with radar). Additional sonar equipment determines the depth of the target.

Sonar is most frequently active—that is, an ultrasonic sound pulse is transmitted and the echo detected as described above. However, the sonar transducer can also be used to pick up sounds in the water, such as the sound of a submarine's propellers beating the water, or the sounds of machinery in the submarine's hull. (Or the sounds of shellfish clapping their pincers, or whales grunting or squealing, or other distractions of subsurface animal life.)

Sonar is the principal method now known for detecting underwater targets that are not themselves radiating sound signals. But the fact is that the principal factor limiting the success of antisubmarine warfare at this time is the limitations of sonar equipment. Although sonar is in some ways analogous to radar in the principle of its operation, it is several orders of magnitude more limited in range, is much less accurate in establishing target bearing and range, is even more limited in determining depth, is much more severely affected by environmental factors such as variations in water temperature and flow at various depths, and is much more responsive to spurious echoes (as from schools of fish, wakes, air bubbles released by the target, and from the ocean floor or surface). Sonar echo interpretation (using both audible and visual responses) is exacting and requires much skill and experience.

One application of passive sonar is in sonobuoys. These are floating unmanned radio transmitters which lower microphones into the water and broadcast the sounds that they pick up. Sonobuoys are generally dropped by fixed-wing aircraft, and analysis of the sound pattern broadcast from several of them will indicate the location of sound-radiating submarines in the vicinity.

Sonar gear is carried aboard surface vessels and submarines. A special adaptation called DUNKING SONAR in which the transducer can be lowered by cable from a helicopter is used to supplement surface ASW forces.

2C6. MAD (MAGNETIC AIRBORNE DETECTION)

Any ferrous object will distort the earth's magnetic field. This distortion can be detected by a sensitive device—Magnetic Airborne Detection (MAD) equipment—that can either be towed by a ship or carried in an aircraft. At present, MAD gear is even more limited in range than sonar. Its principle of operation is applied also in guidance of some weapons.

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D. Delivery Devices

2D1. NOMENCLATURE

Broadly, delivery devices launch, carry, or project a destructive device to the target. Examples are guns, torpedo tubes, rocket launchers, projectors, and depth charge racks. The term weapon is with one major exception properly applied to the destructive unit that is launched, carried, or projected. Thus, a rocket launcher is not, strictly speaking, the weapon in a weapon system, but the rocket itself is; the torpedo tube is not a weapon, but the torpedo is. The major exception is the gun. The gun is normally called the weapon in any system based on guns; a gun projectile generally is not properly called a weapon.

The term "delivery device" for such a weapon as an aircraft bomb or a ship-laid mine refers to the bomb rack and dropping gear or to the minelaying gear, not to the bomber aircraft or minelaying ship—which are vehicles.

2D2. FUNCTIONS OF DELIVERY DEVICES

To function effectively on their targets, all weapons (and projectiles) must either be directed to their targets or to the target area, or programmed so that they will operate properly in the target approach—or they may require both directing and programming. This is done at or before the time of launching either by or through the delivery device, and this function is characteristic of all delivery devices, even the simplest. Directing the destructive unit to the target may be done simply by aiming the delivery device (gun barrel or rocket launcher guide, for example). Or it may be done without aiming (as in torpedo tubes and missile launchers) by conveying program instructions into the weapon either mechanically or electrically. Programming of functions to be performed by the weapon after launching (including the setting of devices which will initiate its explosion upon approach to or contact with a target) is done electrically in some weapons, mechanically in others.

Another function of many delivery devices is to propel the weapon or projectile over all or part of its course, but not all delivery devices do this. Most mines and all aircraft bombs, for example, are conveyed to their targets by their vehicles, and the delivery device functions only to drop them.

2D3. TYPES OF DELIVERY DEVICES

Delivery devices now in use include:

1. Guns, which provide all the propulsion energy to their projectiles, direct them (by the position of their barrels), and program their functioning by adjusting some fuzes or causing them to arm (i.e., become set for action).
2. Rocket launchers, which direct rockets by positioning them. Similar launchers are also used with other weapons that are not classified as rockets.
3. Missile launchers, which position missiles for the initial stages of flight, and feed into them electrically steering and programming information up to the instant of firing.
4. Depth charge and thrown weapon projectors, which propel depth charges or thrown weapons to a selected point on the surface of the water. The weapons sink and function under water. The projectors may function on the principle of either the gun or the rocket.
5. Minelaying gear, which sets mines to perform arming and other functions after launching.
6. Bomb release gear, which initiates the arming process in bombs at the time of release.
7. Torpedo tubes and other launching devices, which set torpedoes to run in a specific direction, and may program them to arm at a specific range, undertake a selected search pattern, or perform other functions.

Delivery devices which the student will encounter on surface vessels will be taken up in further detail in later chapters.

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E. Control Units

2E1. FUNCTION OF CONTROL UNITS

As previously defined, control units in a weapon system develop, compute, relay, and introduce data into a delivery unit, weapon, or both, in order to direct, control, or guide the weapon to the target and cause it to function in the desired way.

2E2. TYPES OF CONTROL UNITS

The devices that perform these or allied functions, in whole or in part, include:

1. DATA TRANSMISSION SYSTEMS (generally electrical) to convey the target data developed by detecting units into the remainder of the system, to convey these and other data among the components of the system, and to convey aiming and programming data to the delivery device and to the weapon.
2. COMPUTER DEVICES (either mechanical or electrical, sometimes both) to process the input data from the detecting units and other sources and put out aiming and other programming data required to cause the weapon to reach its target and function at the proper time.
3. INDICATORS (sometimes called repeaters) to display data inputs and outputs as required at various locations on the ship.
4. DIRECTORS, which with the aid of detecting devices discussed earlier in this chapter establish target location, which may incorporate computer devices to function as described in No. 2 above, and which always incorporate data transmission components.
5. REFERENCE DEVICES, such as stable elements, which establish reference planes to stabilize lines of sight, aiming positions, etc. These are always gyroscopically stabilized, though devices based on other principles may be used in emergencies.
6. ELECTRONIC CONTROL DEVICES intended to control guided missiles. These are generally radars or radio transmitters and receivers.
7. TRAINING AND ELEVATING GEAR. Most types of delivery units must be positioned to specific angles with respect to reference planes and lines in order to initiate correctly the launching of the weapon or projectile. This may be done through gear trains driven by hand, and this kind of manual operation is generally provided for emergency use or for adjustment of the equipment. In normal service, however, this function is performed by electric or electric-hydraulic power drives, controlled through data transmission systems by computers or directors. Training gear positions the delivery unit by rotating it in a plane parallel to the ship's deck; elevating gear positions it by rotating it in a plane perpendicular to the deck.

F. Weapons and Projectiles

2F1. FUNCTION OF A WEAPON OR PROJECTILE

The end purpose of detection equipment, delivery units, and control systems is to get the destruction unit (weapon or projectile) to meet the target. It is then the function of the destruction unit to destroy or inflict maximum damage on the target. Except for small-size gun projectiles (those used in small arms, and those used in calibers up to 40-mm), most weapons and projectiles used in combat operation are loaded with explosive and equipped with devices to set off the explosive at the proper time. With some weapons and projectiles, the proper time is the instant the target makes physical contact with the weapon. With others (especially those designed to penetrate targets protected by armor or concrete) the proper time is after penetration. Still others are intended to explode when the target is in the vicinity of the weapon.

2F2. ELEMENTARY WEAPON COMPONENTS

All weapons and projectiles have the following functional components, which take different physical form in different varieties:

1. A CONTAINER OR BODY which houses the other internal components. The body may

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have such other functions as piercing armor, breaking up into high-velocity fragments when the weapon or projectile explodes, or (by its streamline shape or by aerodynamic fins) improving ballistic characteristics.

2. A DETONATING DEVICE (called a fuze, pistol, exploder, detonator, etc.) which initiates explosion at the proper time, and includes safety devices to prevent explosion prematurely.

3. A BURSTER consisting of a quantity of explosive material. The main "payload" of the weapon may, more rarely, be a chemical agent, with a small amount of explosive to release or scatter it. Weapons for training purposes may contain still other payloads.

Weapons of some types have their own propulsion systems. The outstanding examples are guided missiles, torpedoes, and rockets. Gun projectiles, aircraft bombs, and most mines do not incorporate propulsion systems. Except for rockets, weapons with propulsion systems incorporate guidance and control devices.

2F3. CHARACTERISTICS OF WEAPONS AND PROJECTILES NOW IN USE

Table 2-1 summarizes in generalized terms the characteristics of the principal types of weapons and projectiles now in use. In interpreting the table, bear in mind that it is intended only as an aid in understanding the usual characteristics of contemporary weapon types. Some weapons combine the characteristics of more than one type, and don't fit neatly into the pigeonholes. Also be wary of nomenclature; e.g. some weapons not called rockets are at least in part rocket propelled.

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Table 2-1.—TABLE OF WEAPON CHARACTERISTICS

Weapon or projectile	Propulsion incorporated	Guidance-control system incorporated	Usual type of target	Delivery unit	Vehicle	Guidance-control system in vehicle
Gun projectile	None	Fuze; no guidance control.	Air, surface, or land target.	Gun	Aircraft or surface craft.	Gun fire control system or gun mount sights.
Aircraft bomb	None	Fuze; no guidance control.	Surface or submerged target.	Bomb release gear.	Aircraft	Bomb sight.
Rocket[1]	Rocket propellant	Fuze; no guidance control.	Air, surface or land target.	Rocket launcher	Aircraft or surface craft.	Special fire control system.
Guided missiles[2]	Rocket or jet	Full guidance, various types.	Air, surface, submarine, or land target.	Missile launcher	Aircraft, surface craft, or submarine.	Special fire control and guidance system.
Depth charge[3] and other A/S thrown weapons.	Either none, gun-type propelling charges, rocket propulsion.	Pistol (equivalent to fuze); no guidance control.	Submerged targets.	Release rack, guntype projector, or rocket launcher.	Surface craft	ASW fire control system.
Torpedo	Screw propeller driven by electric motor or steam turbine; some types have rocket propulsion for initial stage.	Gyroscopic and programmed guidance; fitted with exploder.	Surface craft and submerged targets.	Torpedo or rocket launcher, torpedo tubes, launching racks.	Aircraft, surface craft, or submarines.	Torpedo or ASW fire control system.
Mine[4]	Usually none; one has electric motor propulsion so it can reach a location inaccessible to the minelayer.	Programmed operation; fitted with pistol.	Surface craft and submarines.	Minelaying gear.	Surface craft or aircraft.	None (except for propelled type).

[1] Use also in launching ASW weapons.
[2] See second volume of this series.
[3] One type rocket-propelled; several types gun-launched.
[4] All mines are passive weapons that lie in wait for targets.

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CHAPTER 3

BASIC SCIENCES FOR NAVAL ORDNANCE AND GUNNERY

A. Introduction

3A1. LAYING THE FOUNDATION

SCOPE. This chapter deals with the scientific principles—and particularly the practical applications of those principles—that should be part of the background of every junior naval officer. Without an understanding of these principles, a naval officer would be at a loss to comprehend the operation of even the oldest and simplest shipboard weapons. As for the new "sophisticated" ordnance, even the casual skimmer of newspaper headlines knows that our recently developed weapons demand a broad and sound scientific background.

This chapter will not, in and of itself, enable the reader to explain every detail of a specific weapon or installation. It should, however, prepare him to read, without great difficulty, the ordnance publications that do give complete details. It should also help him to understand a variety of standard components—such, for example, as gear trains—that are used in many types of machinery, ordnance and non-ordnance alike. Finally, it should help him to understand the general operational cycle (though not the fine details) of so complex a system as a train or elevation power drive.

For convenience, the chapter has been divided into separate sections dealing with mechanics, hydraulics, electrical devices, optics, and sound. In any specific ordnance device, principles from more than one of these areas are frequently combined.

Whenever practicable, the illustrative examples have been selected from naval ordnance. Some types of ordnance equipment, however, are not well suited to serve as preliminary examples, and simplified examples have been used instead.

A reader who has studied (or is now studying) general physics will recognize many of the topics in this chapter. He may also notice that the chapter passes lightly over large classes of conventional textbook material, and omits some classes altogether. An omission does not mean that a topic lacks importance. It simply means either (1) that the omitted topic is not closely related to ordnance problems or (2) that it will be covered later in this text, or possibly in another course.

Some readers may desire amplified explanations at the present time. Abundant supplementary reading in the background sciences may be found in the physics section of any college library. Frequently it may also be found in a good public library.

3A2. SOME FUNDAMENTAL DEFINITIONS

If one specialist is to understand another specialist correctly, the two men must agree exactly as to what they mean by certain important "technical" words. In the sciences, including physics, some of the specialized words are long and difficult. Frequently these long words have been derived from classical Greek or Latin—languages which, being "dead," are no longer subject to change. Or they may be derived from the names of renowned scientists of the past. This is especially true of units of measurement such as ohm, volt, and ampere.

Other scientific words look deceptively simple, for they have been taken from everyday speech. The scientist, however, does not use common words in a loose sense. He gives each a single precise meaning, thus restricting the word to one out of the many values it may have in social conversation. This meaning the student

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must learn and remember. Such words are generally used in this text in their precise scientific sense.

The paragraphs below give a few basic definitions that are used in the several branches of physics. Other definitions, more specialized in their applications, will be given in later sections of this chapter.

FORCE. A force is a pull or push on a material object that causes (or tends to cause) the object to move or (if moving) to change its direction or rate of motion. A force can be present even if no motion or changes in motion actually result from it. This can happen if the force is balanced by an equal force in the opposite direction.

PRESSURE is force per unit area. Obviously, the amount of pressure depends on two things—the amount of force and the area it's applied to. Imagine a 10-pound weight on your desk. It's applying a force of 10 pounds to the desk top. But what pressure is it applying? If the bottom of the weight has an area of 10 square inches, the weight applies a pressure of one pound per square inch. But if the bottom of the weight has an area of only one square inch, then it applies a pressure of 10 pounds per square inch.

WORK. As understood by the physicist, work is performed when (and only when) a force called an effort moves a material object against an opposing force called a resistance. Motion is the important idea in this definition. A seaman who simply stands and holds a 50-pound projectile may become tired, but he is not performing work in the physicist's sense of the word. But, if he lifts this projectile three feet in opposition to the 50-pound downward pull of gravity, he is working. The exact amount of work he does is 50 x 3, or 150-foot pounds. In short, work is force acting through distance.

POWER. The word power, as used by the physicist, adds the idea of time to the idea of work. If our seaman hoists his 50-pound projectile 10 feet in 2 seconds, his power is $\frac{50 \times 10}{2}$, or 250 foot-pounds per second. Power, then, is the rate, or speed, of work. When time is important, as it usually is in combat, power becomes a major consideration. Many shipboard operations are mechanized because a machine has more power—that is, can move a heavier load in a shorter time—than the human labor available.

ENERGY. The capacity for doing work is known as energy. There are many sources of energy. The CHEMICAL energy released by a burning propellant moves a projectile toward its target. This chapter will be concerned with mechanical, hydraulic, electrical, radiant, and acoustic forms of energy.

A substance or mechanism that is ready to perform work, but is not actually performing it, has POTENTIAL energy. By virtue of their chemical composition, propellants and high explosives in magazine stowage have potential energy.

Energy in action is called KINETIC energy. A burning propellant has kinetic energy.

The total amount of energy in the world remains always the same (except that matter can be converted to energy in nuclear reactions). This statement is the law of the conservation of energy. Energy can be converted from one form to another, as when the kinetic energy of a waterfall drives a generator to produce electrical energy, which in turn drives a motor to produce mechanical energy. In any of these conversions, at least a small amount of energy becomes lost to the user, because radiation or internal friction causes it to be dissipated as heat. Designers of power equipment try to keep the incidental losses of energy as low as possible.

MASS. Mass is a fundamental property of all matter. In elementary terms, the mass of a body is the quantity of matter in it. When a force acts on a mass, it tends to move it or to change its motion (depending on the direction of the force). Gravity acting upon a mass at the earth's surface exerts a force tending to pull the mass toward the center of the earth. The amount of this pull we call weight. If we transferred the mass to the moon, whose gravity is only a fraction of the earth's, its weight would be different, but the mass would be the same.

INERTIA AND ACCELERATION. As we have said, it takes a force acting upon a mass to get the mass to move, or to change the mass' motion. In this sense, the mass resists the force. This property of mass is inertia. For a given force, the greater the mass, the greater the inertia, and the smaller the change in motion. Any change in the motion of a mass is acceleration. Acceleration may be positive (speeding up) or negative (slowing down).

MOMENTUM. A mass in motion persists in moving because of its inertia, and will resist forces that tend to stop it. This tendency to continue moving is momentum. Momentum is proportional to both mass and rate of movement,

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and is equal to their product. Thus a projectile weighing 5 pounds and moving at 2,000 feet per second has the same momentum as a motor launch weighing 2,000 pounds and moving at 5 feet per second. These are examples of momentum in masses moving in a straight line. A rotating mass also has momentum. In addition to the effect of its mass-inertia, the rotational momentum of a spinning mass such as a heavy-rimmed wheel will cause it to resist any force that tends to change the direction in which its axis of rotation is pointing. This is why a top remains upright as long as it maintains sufficent rotational speed. This effect constitutes the operating principle of the gyroscope, described in the next section of this chapter.

CENTRIFUGAL FORCE. This is a special case of inertia. Any spinning object develops a centrifugal force. The rim of a turning wheel, for example, pulls outward on its spokes. The strength of the centrifugal force varies as the square of the speed at which the wheel is turning. For double the speed of rotation, for example, the centrifugal force will increase four times; for triple the speed, the centrifugal force will be nine times as great.

3A3. NEWTON'S LAWS OF MOTION

Sir Isaac Newton is famous for his enunciation of the law of gravitation, but equally fundamental in physics are his three laws of motion. These are the basis for the sciences of mechanics and statics. A clear understanding of them and their implications is essential for the realistic comprehension of any mechanical device or system. The laws are:

1. First law. A body at rest tends to remain at rest and a body in motion tends to continue moving in a straight line unless (in either case) the body is acted on by some unbalanced force. (In applying this law to practical examples about you, always remember that friction, gravity, and air or water resistance must be taken into account).

2. Second law. A body acted on by an unbalanced force will accelerate in the direction of the force, and the acceleration will be directly proportional to the unbalanced force and inversely proportional to the mass of the body. (Note that this idea has already been presented implicitly in the preceding article's discussion of acceleration and momentum. In fact, the law can be restated more briefly in terms of momentum.)

3. Third law. To each action there is an equal and opposite reaction. ("Action" here is the force which body No. 1 exerts on body No. 2; reaction is then the force which body No. 2 exerts on body No. 1. A book lying on a table exerts a push downward on the table equal to its weight; the table's reaction pushes the book upward with equal force. The rotating screw of a ship pushes the water rearward; the water reacting against the screw exerts an equal forward push. The combustion chamber and exhaust nozzles of a rocket exert backward thrust on the exhaust gases; the gases react with an equal forward push on the rocket.)

B. Basic Principles of Mechanics

3B1. FUNDAMENTALS OF MACHINERY

All machinery—no matter how complex it may be—can be broken down into simple components or basic mechanisms. These include the lever, the wheel and axle, the pulley (block and tackle or block and falls in Navy parlance), the inclined plane, the screw, the gear, the shaft, the cam, the spring, the clutch, the pawl and ratchet, the piston and cylinder, the friction brake, the roller or ball, the bearing, and so on. Some of these are actually applications or rearrangements of others. (Examples: the wheel and axle is a special type of lever; a screw is a special type of inclined plane.)

Figure 3B1 shows representative examples of five of these basic mechanisms. They illustrate one objective—to do work or transmit motion by moving a load (often called the resistance) through application of force or effort. (Or the force may be used in the mechanism to counterbalance another force.)

Historians and others have attempted to reduce all mechanical devices to six (or some other number) "basic machines," but since different lists include different mechanisms, and

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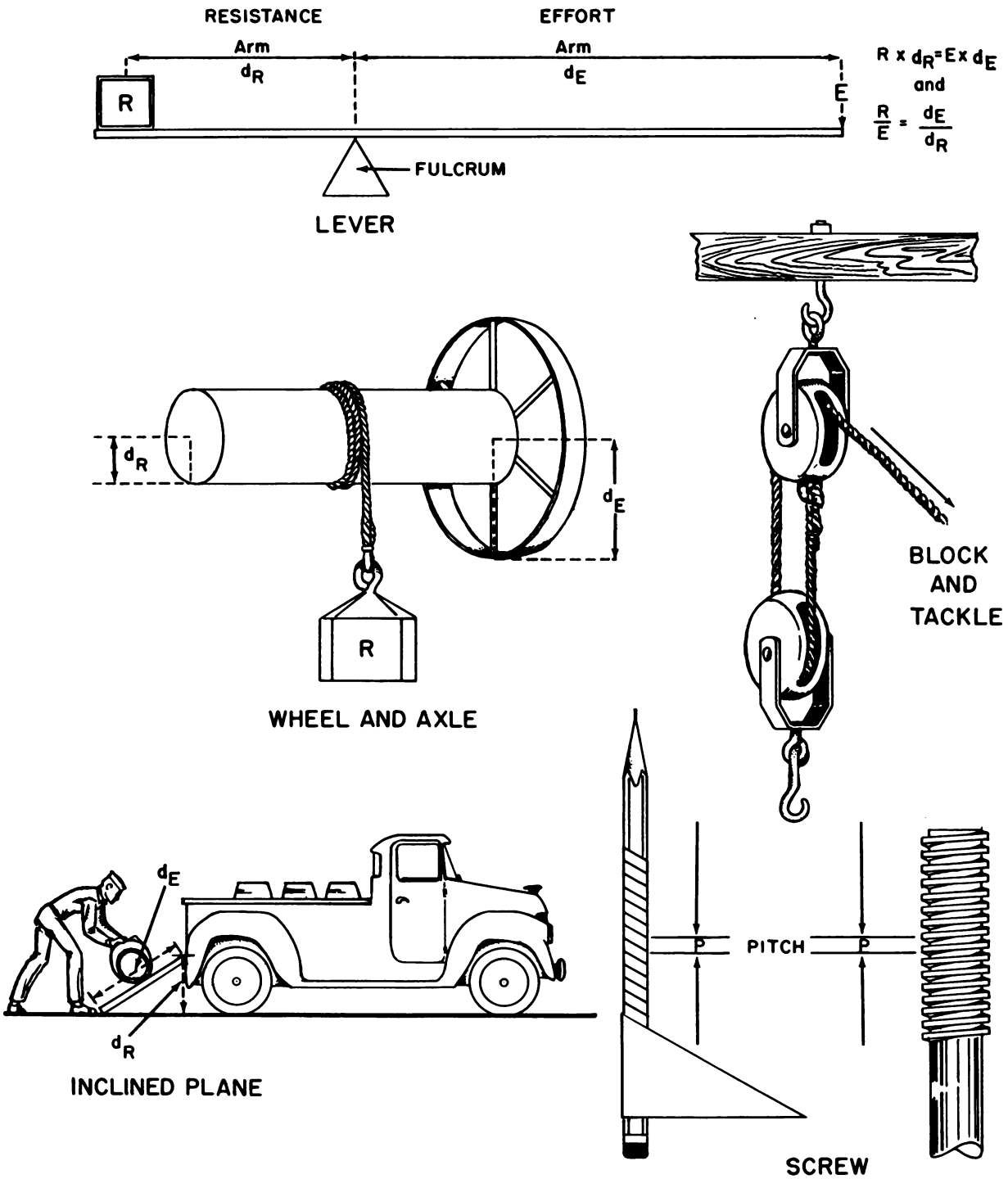

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Figure 3B1.—Five basic mechanisms.

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frequently omit mechanisms as important as those they include, we shall here concentrate on those particularly applicable to ordnance devices, without attempting to develop universal generalizations or niceties of classification.

ANALYSIS OF CERTAIN BASIC MECHANISMS. The lever principle is probably the most fundamental one in mechanics. The drawing of the lever (figure 3B1) shows that a resistance acting at one side of the pivot or fulcrum can be counterbalanced by an effort applied at the opposite side. (In this particular class of lever, the effort is a downward push.) The distance from the fulcrum to the point at which the push of the resistance seems to be concentrated (that is, to the center of gravity of the resistance) is called the resistance arm. The distance from the fulcrum to the effort is called the effort arm.

Balance is achieved when the product of the effort and the effort arm becomes equal to the product of the resistance and the resistance arm. This principle is called the lever formula. It may be expressed mathematically as follows:

$$R \times d_R = E \times d_E$$

in which E=effort,
R=resistance
d_E=effort arm,
d_R=resistance arm.

(Not all texts use the same symbols for the two arms, but all texts teach the same fundamental relationship.)

The ratio $\frac{R}{E}$ (which, as is easily shown, is equal to $\frac{d_E}{d_R}$) is the theoretical mechanical advantage of a machine. In actual practice the mechanical advantage is always lower than the theoretical figure, since part of the effort must be consumed in opposing the machine's internal resistance, or friction.

The wheel and axle can be analyzed as an application of the lever idea. By the term "wheel and axle" the physicist does not mean a wheel that turns about an axle, as in a wagon. He means, instead, a wheel (or part of a wheel) and a shaft that are firmly secured to each other and turn as a single unit. The ordinary doorknob is a wheel and axle in the physicist's sense. So is the crank, which is really a single spoke that acts like a wheel when it is turned. In a wheel and axle, the effort arm is the radius of the wheel (or wheel segment) that the operator turns. The product $E \times d_E$ is known as torque or twisting force, and is expressed in pound-feet, ounce-inches, or similar units. The tool called a torque wrench acts automatically to warn the operator when he has applied the set value of torque to a screw.

Not all basic mechanisms are applications of the lever. The inclined plane is the basis of the wedge, of the screw (i.e., the mechanical component, not the fastening device), of some types of cam, etc. To understand the relation between the screw and the inclined plane, note how figure 3B1 shows that in effect a screw is an inclined plane wrapped around a cylinder, as the hypotenuse of the paper triangle is wrapped around the pencil. The pitch of the screw (P in the illustration) is the distance between threads. A screw must make a complete turn to move a load along a resistance arm equal to P.

The gear principle is the use of meshing teeth to permit mechanical engagement of rotating and reciprocating mechanical components. This makes possible the linking of a number of individual components such as screws, wheels and axles, etc. A wheel becomes a gear when its rim is cut to form regularly spaced teeth that mate with corresponding teeth on another wheel. Usually (but not necessarily) the shaft is firmly fixed to its gear. Gears and shafts will be discussed later in the chapter.

Though they can be—and often are—used alone, the basic mechanisms are frequently combined to form machines or mechanical systems. The next article will deal with these more complex systems.

3B2. MECHANICAL SYSTEMS

MAJOR CLASSES. There are two major classes of mechanical systems—driving machines (often called prime movers) and driven machines. An electric motor is a driving machine; a sump pump powered by the motor is a driven machine. In many small, compact ordnance devices, such as bomb fuzes, compressed springs act as driving mechanisms.

Some machines act simultaneously as driving and driven components. The pump in a gun's electric-hydraulic drive is driven by an electric motor. The pump, in turn, acts to drive a hydraulic motor, and this motor drives the training or elevating devices.

There must always be some connecting link to transmit power between a driving machine and a driven machine. When the two machines are near each other, the link is frequently a

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mechanical one, such as a belt, a chain, or a system of shafts and gears. Under some conditions, enclosed fluids are used to transmit mechanical motion. This use of fluids will be taken up in the section on hydraulics. When the driving and the driven machine are widely separated, electrical transmission is normally used.

BASIC PURPOSES. All mechanisms serve one or more of the following purposes:

1. They may transmit motion, force, or power. As already mentioned, belts, chains, and gearing systems are used for this purpose.

2. Mechanisms with a high mechanical advantage are used to increase a small force to a large one, at a corresponding sacrifice of speed and distance. By using the block and tackle shown in figure 3B1, a man can hoist an 80-pound weight by giving a 40-pound pull. But, to hoist this weight 12 feet, he will have to haul in 24 feet of line.

3. Provided a low mechanical advantage (some fraction less than 1) is acceptable, a machine can increase the speed and extent of motion. If a crank 10 inches long acts through a common shaft to turn a wheel 20 inches in radius, a point on the rim of the wheel will travel twice as many inches, in a second, as the crank does. Since the effort arm, this time, is only half the resistance arm, the applied effort will have to be double the resistance.

4. Finally, a machine may change direction or type of motion. In the lever shown in figure 3B1, a downward effort moves the resistance upward. As will be shown later, gearing systems are effective in changing the direction of motion, and even in converting circular motion to straight-line motion, or vice versa.

PRINCIPAL COMPONENTS. The paragraphs following deal with the principal components of complex mechanical systems. As will soon become evident, these components are either basic mechanisms or connecting devices.

A SHAFT is a cylindrical rod used to transmit turning motion. A shaft may be pinned to input or output gears, or it may have splined or toothed ends that mesh with gears. A shaft is mounted to turn without interfering with other components. Figure 3B2 shows a common type of shaft mounting used in mechanical computation devices.

One shaft may be joined to another by a rigid sleeve, by a flexible coupling, by a universal joint (described later under pivots), by gears, pulleys, or clutches, etc.

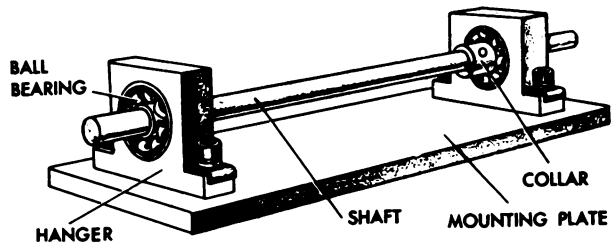

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Figure 3B2.—A representative shaft and mounting.

BEARINGS permit rotation of a shaft with respect to a support that does not rotate with the shaft. A plain or journal bearing (not illustrated) uses a sleeve within which the shaft turns. To reduce friction, the sleeve is generally of softer metal than the shaft. Ball and roller bearings (figure 3B3) substitute rolling friction (which is comparatively small) for sliding friction between surfaces. Thrust bearings are designed to take up an axial thrust while permitting shaft rotation. There is a variety of thrust bearing designs. Jewel bearings are used in very fine machinery. The pointed end of a hard steel shaft rotates in a V-shaped depression in the fixed jewel (usually a sapphire or ruby).

A PIVOT is a fixed pin or short axis that permits one part to turn with respect to another. Pivots are closely related to bearings. The main distinction between them is that pivots are generally associated with limited arcs of rotation. An arrangement of pivots called a universal joint (fig. 3B4) is used to connect rotating components (for example, a pair of shafts) that must be permitted to swivel as they rotate.

A CRANK is an arm (or pair of arms) keyed to a shaft in such a way as to impart or receive motion. The common exterior or side crank is manually rotated to introduce hand inputs into a mechanical system. As mentioned earlier, this is essentially one spoke of a wheel. Internal cranks take various forms. One of the commoner forms found in naval ordnance is the bell crank shown in figure 3B5. This type is used to carry push-pull motion around corners. Cranks may also be used to convert turning motion to back-and-forth (reciprocating) motion (for example, in certain types of motor-driven reciprocating pumps) or vice versa (for example, in internal combustion engines).

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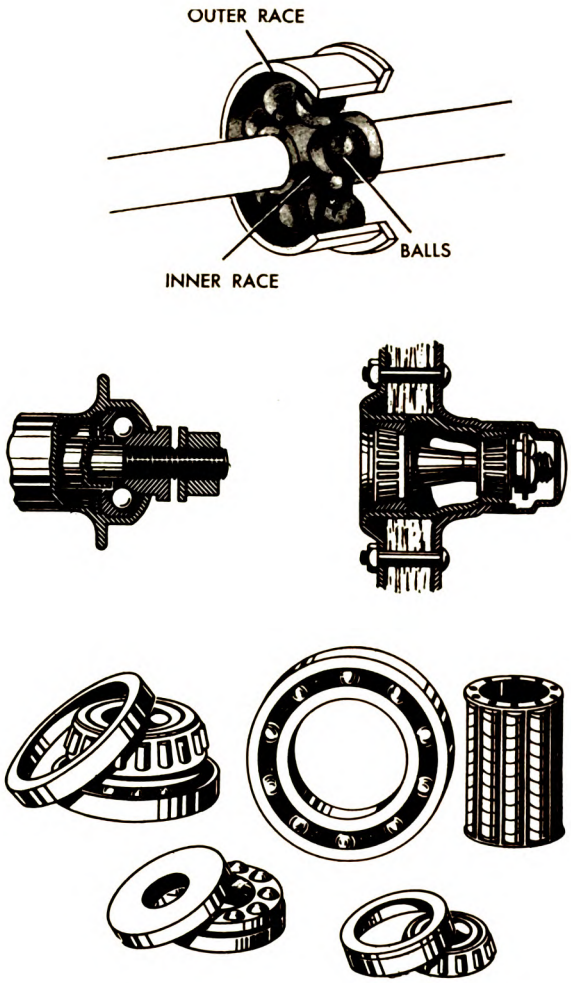

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Figure 3B3.—Representative bearings.

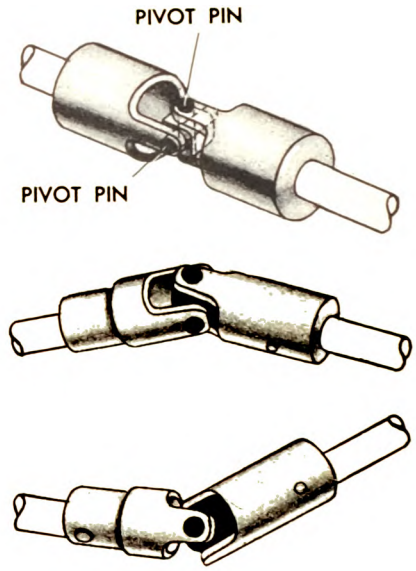

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Figure 3B4.—Pivoting arrangement in a universal joint.

A LINKAGE is a system of bars, cranks, and other lever-like components, connected to fixed members and to one another in such a way that an input force causes a desired movement of the movable members. Figure 3B5 shows a linkage used in the loader for the 3-inch rapid-fire gun. When the vertical shaft moves upward, the horizontal gates are pulled together to close; when it moves down, they open.

Of all the mechanical components used in ordnance machinery systems, few are more numerous or more varied than the gears. They are used to transmit motion, to change the direction or type of motion, and to increase or decrease speed. Also, as a later article will explain, they are used to perform the four arithmetical processes (addition, subtraction, multiplication, and division). The serious student will regard the discussion of gears in this chapter as a mere introduction to a large and fascinating topic.

As has been said before, many (but not all) gears are wheels with teeth that mesh and permit one wheel (the driving gear or driver) to turn the other wheel (the driven gear) without slipping.

Figure 3B6 shows a simple gearing arrangement. Here the driver and the driven gear have the same diameter and the same number of teeth. Necessarily, therefore, they turn at the same speed, though in opposite directions (one clockwise and one counterclockwise). The shafts, likewise, turn at the same speed and in opposite directions.

The ratio of the number of teeth on the driver to the number of teeth on the driven gear is called the gear ratio. In figure 3B6, the gear ratio is 1:1.

Gears that have radial teeth, as in figure 3B6, are called spur gears.

A designer may wish two parallel shafts to turn in the same direction. They will do this if he places an idler between the driver and the driven gear, as shown in figure 3B7. This idler

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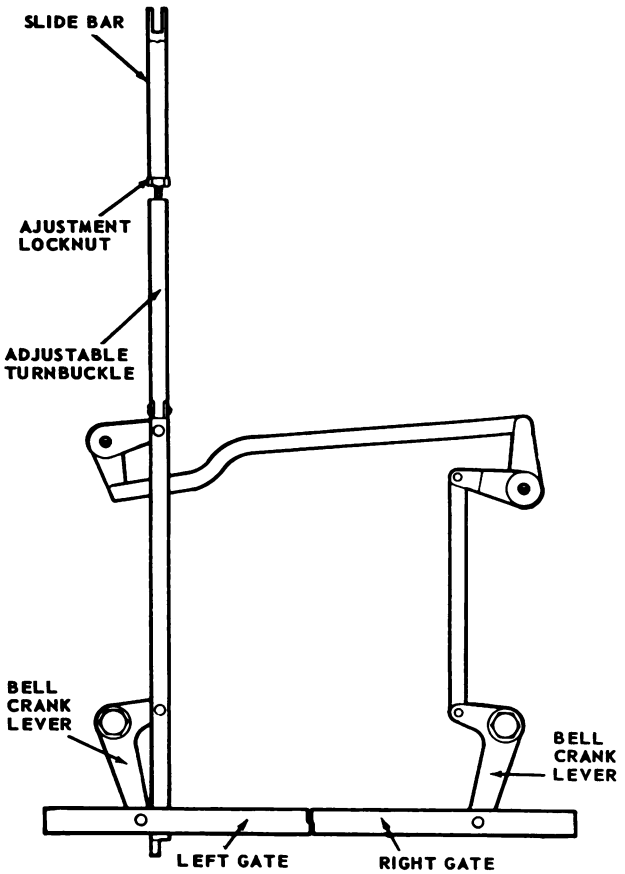

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Figure 3B5.—A typical ordnance linkage (gate-operating linkage, 3-inch rapid-fire gun loader).

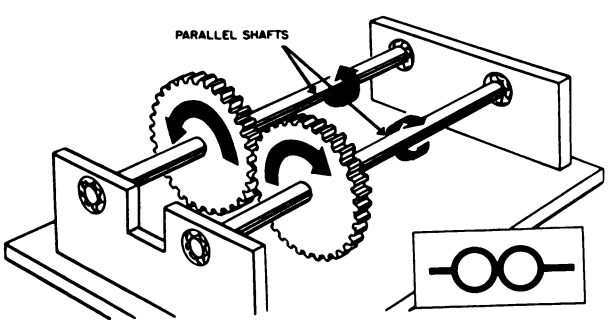

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Figure 3B6.—Spur gears with a 1:1 ratio.

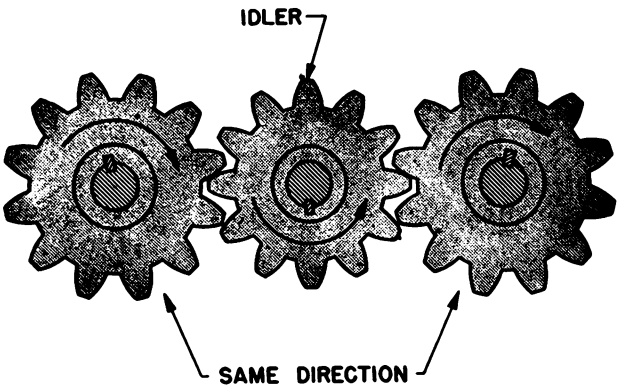

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Figure 3B7.—The principle of the idler gear.

serves only to change the direction of motion; it has no other use in the system.

To produce a difference in speed between two gears (and the related shafts) the designer makes the driven gear larger or smaller than the driver, as required. If the driven gear has four times the circumference (and four times the number of teeth) of the driver, it will take four times as many seconds to make a complete revolution; that is, its speed will be a quarter of the speed of the driver.

To turn a driven gear and shaft faster than a driver, as is frequently desired, the designer makes the driven gear smaller than the driver. The smaller gear of a meshing pair is frequently called a pinion.

The shafts in a gearing system need not be parallel. As figure 3B8 shows, they may be placed at right angles or at some other desired angle. Bevel gears (fig. 3B8) can be designed to transmit motion at almost any angle. Bevel gears that are at right angles are called miter gears.

Some gears do not need to turn through a complete circle. The mechanism may have limit stops that restrict the travel of a pinion to a certain number of revolutions clockwise and an equal number counterclockwise. To save space and weight, the gear driven by this pinion can be a segment, or sector gear, rather than a circle. Figure 3B9 shows a sector gear.

Under some conditions a limited-travel gear need not be an arc. Sometimes it can (and indeed MUST) be a straight bar with gear teeth, or a rod with a specially designed screw thread. The

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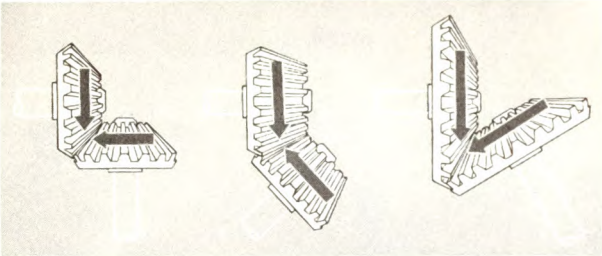

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Figure 3B8.—Bevel gears.

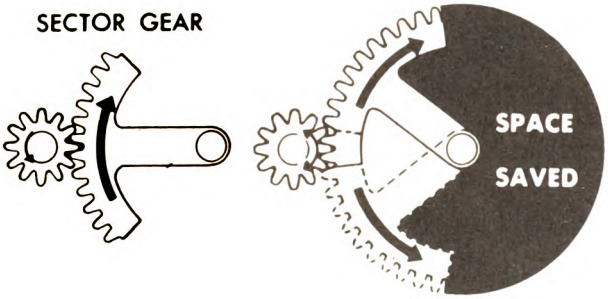

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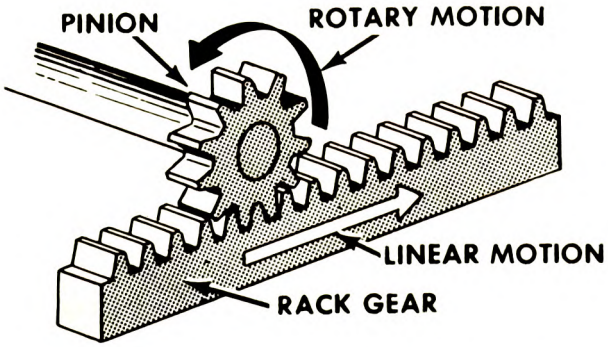
Figure 3B9.—How a sector gear saves space.

bar-type gear is called a rack (fig. 3B10); the screw-type gear is called a worm, and its mating gear is called a worm wheel (fig. 3B11).

A single-thread worm turns its worm wheel one tooth for each turn of the worm, and a



5.22.13

Figure 3B10.—A rack makes conversions between rotary motion and linear motion.

double-thread worm turns its wheel two teeth for each turn of the worm. Worms may have three, four, or more threads. The number of wheel teeth turned for each revolution of the worm always corresponds to the number of threads on the worm.

Worms are often used where great reductions in amount of rotation are needed, because the ratio of rotation between the worm and its wheel is usually large. Since each thread of the worm moves only one tooth of the wheel the gear ratio between worm and wheel is:

$$\frac{\text{The number of threads in the driving worm}}{\text{The number of teeth in the driven wheel}}$$

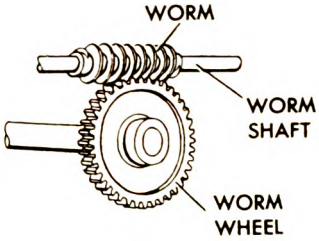


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Figure 3B11.—A worm and worm wheel.

In a single-thread worm with a 100-tooth wheel, the worm must make 100 revolutions for one complete turn of the worm wheel. (The gear ratio is 1:100.)

Sometimes the worm wheel drives the worm. This is possible only when the slope of the worm threads is greater than 5°.

The rack converts rotary motion to linear motion when it is driven by a pinion. A rack with two sets of teeth may serve simultaneously as a driver and a driven gear. When the rack drives, the mechanism converts linear into rotary motion.

Another device for converting rotary motion to linear motion is a screw with a travelling block (fig. 3B12). The block is restrained in such a way that it cannot turn with the screw. As the screw turns, the block walks along the threads. Screw-type elevating gear in older gun turrets uses this principle, and it has other ordnance applications.

Figure 3B13 shows spur gears of several sizes, bevel gears, a screw with a travelling block, a rack (the T-shaped member) moved backward and forward by this block, and, finally, a gear that converts the straight-line motion of

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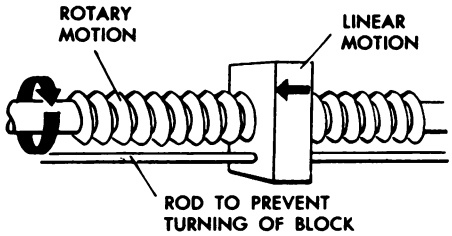

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Figure 3B12.—The principle of the travelling block

the rack to rotary motion. For the sake of simplicity, the draftsman has not shown the teeth on the various gears.

The input enters this system through the handcrank. The designing engineer has assigned an arbitrary input value of 400 knots to each complete revolution of the handcrank. Numerals indicate the gear ratios other than the 1:1 ratio of the first pair of bevel gears. The figure is introduced at this time to show a representative but fairly simple example of the gearing and shafting used in naval ordnance. Somewhat later, the mathematical aspects of the figure will receive some attention.

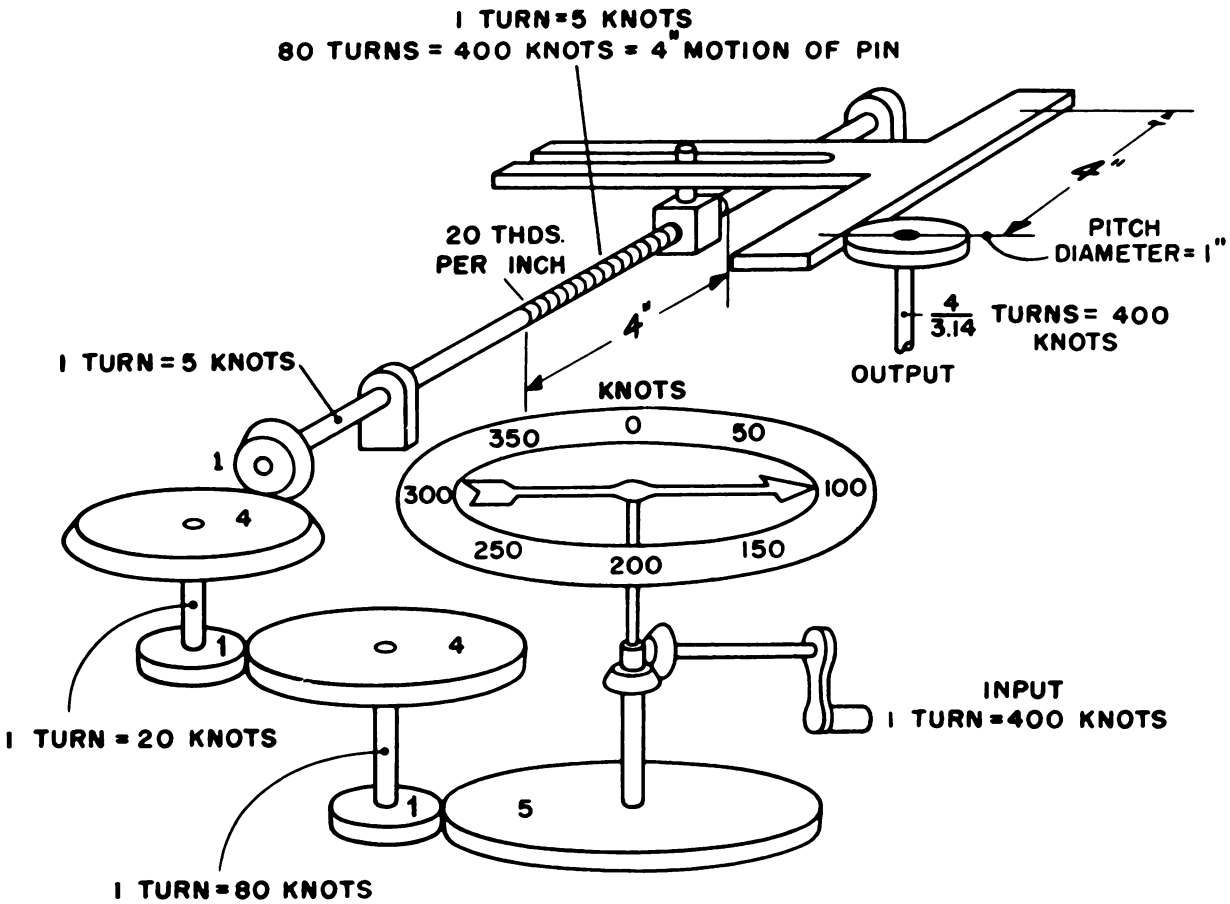

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Figure 3B13.—A representative gearing system used in naval ordnance.

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A DIFFERENTIAL is an arrangement of gears and shafts that accurately and continuously combines two variable inputs to produce a single output (or, conversely, as in the rear end of an ordinary automobile, breaks a single input into two outputs that vary as required).

In figure 3B14 a typical differential has been partially cut away to show the four bevel gears and the spider shaft that are the heart of the mechanism. This is a common differential design, though there are others.

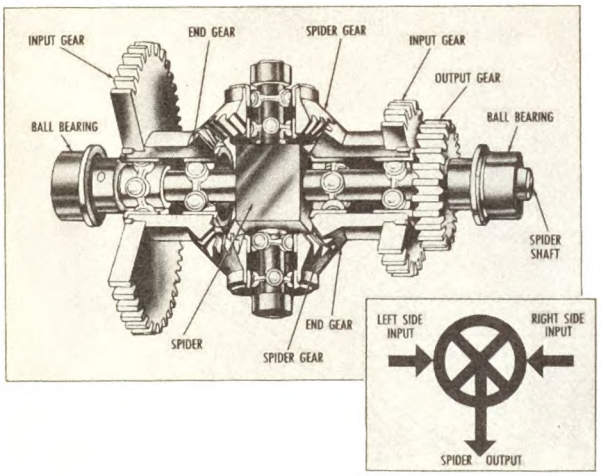

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Figure 3B14.—A typical differential.

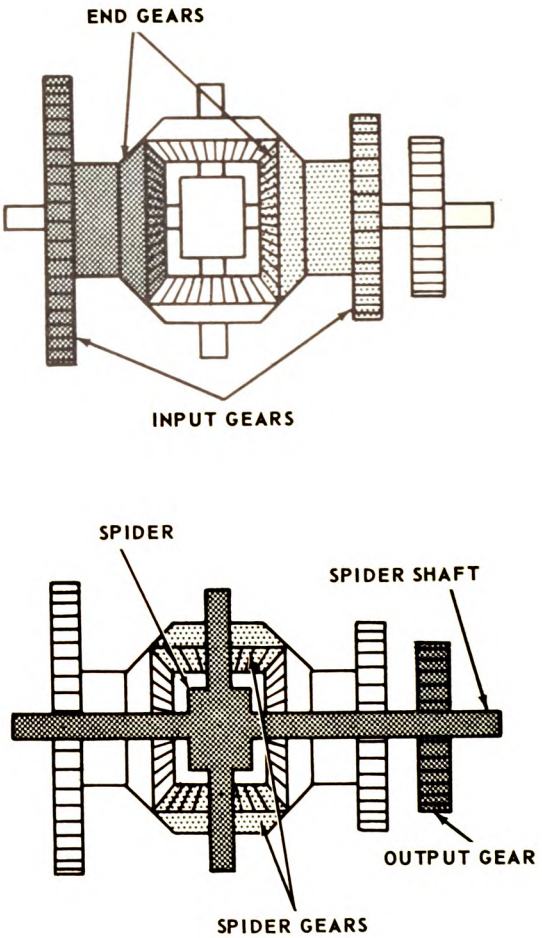

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Figure 3B15.—Gear relationships within a differential.

The simplified drawings in figure 3B15 will clarify the relationships within the differential.

The two bevel gears on the sides of the differential are its end gears. Each end gear is firmly joined to a corresponding spur gear. This spur is the input gear through which inputs from another part of the mechanism enter the differential. Each end gear and its input gear make up a side of the differential.

The two bevel gears above and below, meshing with the end gears, are the spider gears. The cross shaft and the spider gears make up the spider. The cross shaft is pinned to a long shaft called the spider shaft.

The spider gears are not pinned to the cross shaft in the usual gear-and-shaft relationship. Instead, these gears are free to rotate about their shaft on precision bearings. Likewise the two sides are free to rotate independently about the spider shaft. The output gear of the differential, however, is securely pinned to the spider shaft and rotates with it.

Figure 3B16 shows how the spider gears work. When a side receives an input, the input gear and its attached end gear turn. This action drives the two spider gears, and in so doing turns the spider and the spider shaft, with its attached output gear.

If only one of the two sides receives an input, the opposite end gear will remain stationary while the two spider gears walk around it. The output will then vary with the single input.

If both sides receive inputs in the same direction, the movement of the spider will be proportional to the sum of the two inputs.

If the two sides receive inputs in opposite directions, the movement of the spider will be in

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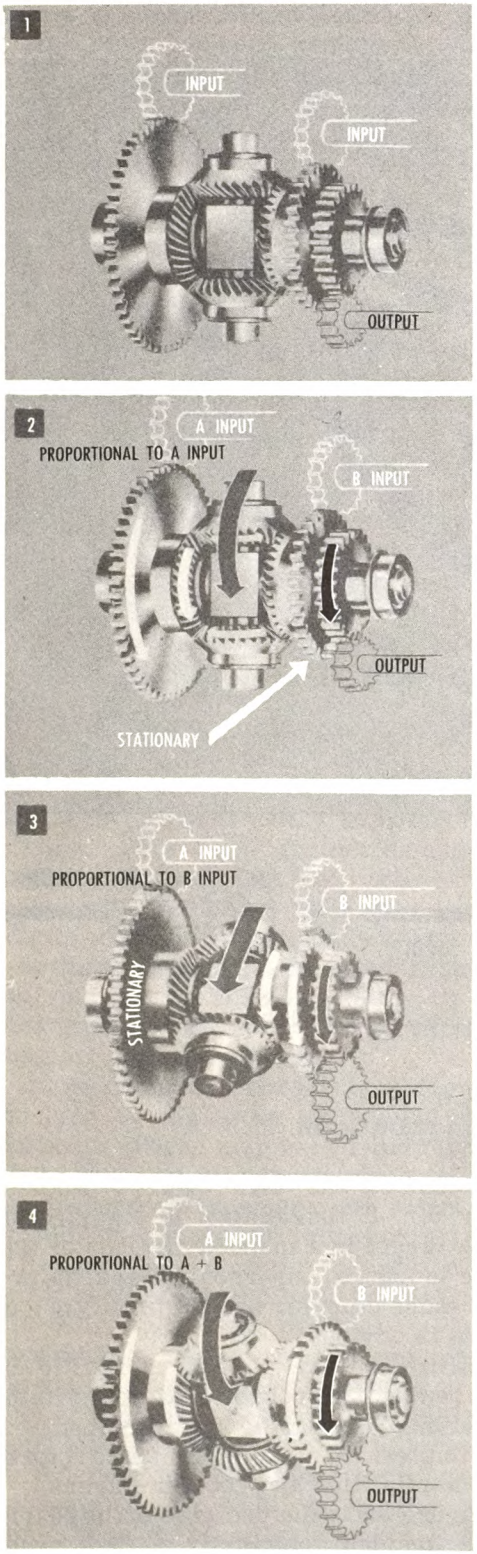

110.9

Figure 3B16.—How a differential works.

the direction of the larger input, and will be proportional to the difference between the two inputs.

If the two inputs are equal and opposite, the spider gears will turn, but the spider shaft will not move.

Because the spider gears are free to roll between the two end gears, the revolutions of the spider always represent half the sum (or difference) of the two inputs.

This short description has shown that the differential can be used to perform additions and subtractions. In fire control devices it is used for that purpose.

Like a gear and shaft, a CAM is a mechanical device for receiving inputs and transmitting outputs. As will be shown later, cams are capable of showing mathematical relationships that cannot be expressed in terms of simple gearing and shafting.

Cams vary greatly in design. Every cam, however, has some sort of shaped surface—a groove, a ridge, or a contour—that is positioned by the input force. Every cam has also an output device, called a follower, that bears against the shaped surface and is positioned by it.

One type of cam has a uniform spiral groove. Each point on this spiral corresponds to an output that is directly proportional to an input from the driving pinion shown at the lower right in figure 3B17. The cam follower is the small cylinder shown as a phantom in the illustration.

The cam shown in figure 3B17 can rotate either clockwise or counterclockwise, depending on the direction of the input. Rotation in one direction forces the follower (and with it the attached follower block and the output pin) outward from the center, along the straight-line slot. A reversal of the direction of rotation forces the follower back toward center. Though the follower itself never touches the zero position at the exact center of the cam, the output pin is offset enough to allow a zero reading to be taken.

This cam is a positive-action type. This means that its follower is keyed to the groove in such a way that it is forced to move every time the cam moves. Some cams, however, have followers that move only when they are held against the cam by gravity, spring action, or some other force that is free to operate only at some stages of the mechanical action.

Cams can be used to control or position other mechanisms. Shipboard guns, for example, have firing cutout cams that act to interrupt firing

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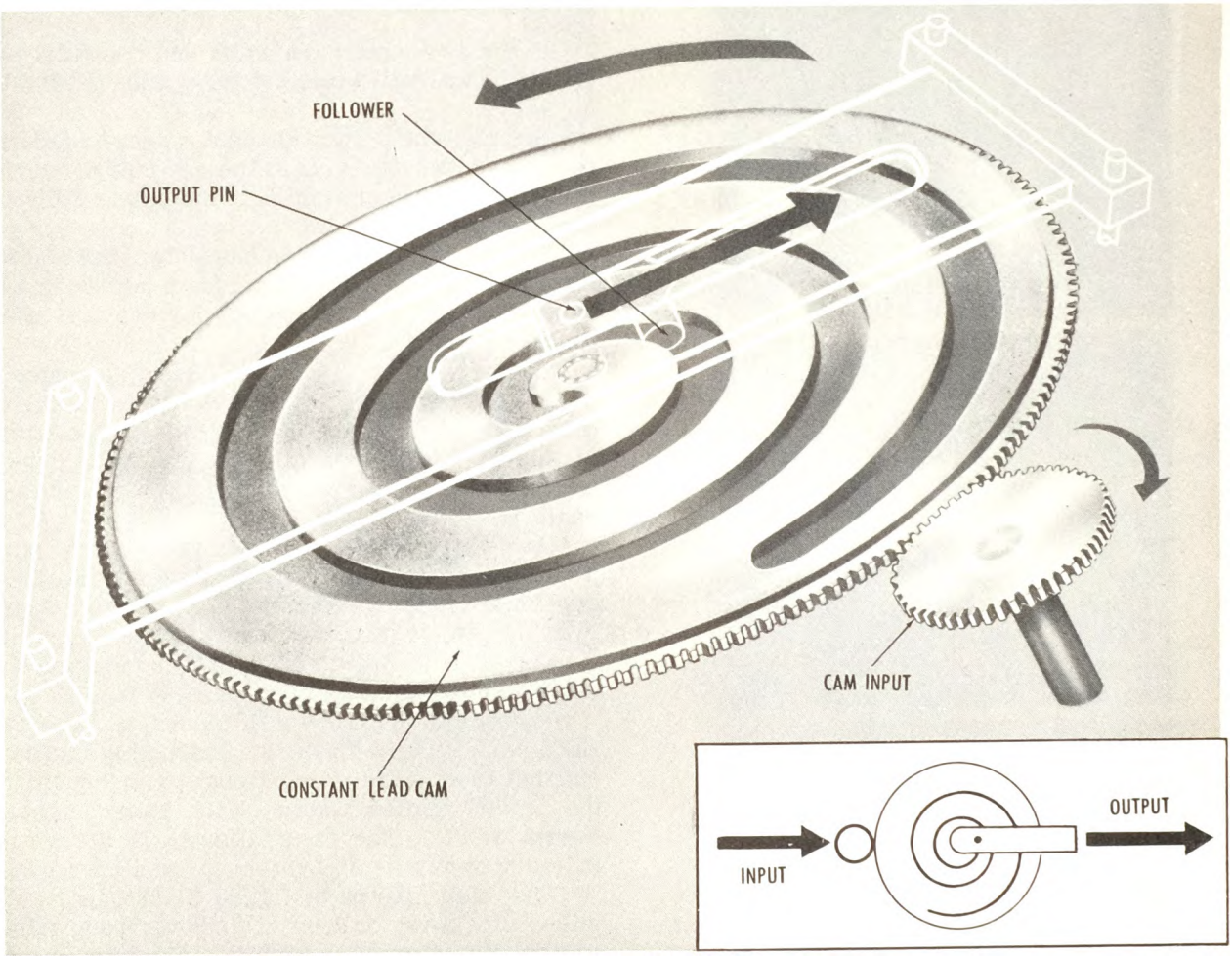

110.10

Figure 3B17.—A positive-action spiral cam.

when the gun is pointing in a direction that endangers permanent shipboard installations. But many cams are special-purpose mathematical devices. As such, they will be discussed in the next article.

3B3. MECHANICAL COMPUTING DEVICES

The problem of hitting a distant, rapidly moving target from a maneuvering ship is much too complicated to be solved by mental arithmetic, or even by hand-operated slide rules. When a conventional gun is fired, some two dozen factors may enter into the fire control problem. (For a discussion of the fire control problem see chapter 5.) If the weapon is a guided missile and the target is a manned aircraft or a guided missile moving at supersonic speed, the problem is still more complex and the futility of longhand methods is obvious.

MACHINES CAN SOLVE THE PROBLEM. As the reader has probably noticed, certain basic mechanisms can hardly be described, even in their simplest terms, without some reference to their potentialities as problem solvers.

In figure 3B13 the designer of the gearing and shafting decided arbitrarily that one revolution of the input crank should represent 400 knots. He could have selected any other figure, had he found it better suited to his purpose; a crank

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revolution, as such, has no mathematical significance until one has been assigned. When an input value has been selected, however, every transmitted value in the entire gearing system varies with the input, following the fundamental law of proportion:

$$a:b = c:d.$$

A GEAR TRAIN, then, is one means of representing mathematical relationships.

Unfortunately, many factors in the fire control problem do not vary in accordance with the laws of direct proportion. These factors, too, can be expressed in terms of mechanical motion. By using the basic mechanisms described thus far, plus certain specialized modifications of those mechanisms, the Navy's mechanical computers set up and solve problems that involve algebra, trigonometry, and even calculus. Related mechanisms either position the gun or launcher automatically or give operating personnel the information they need.

TYPES OF COMPUTERS. A computer may be of the digital or the analog type. It may be mechanical, electrical, or a combination of both. We are here concerned only with mechanical computation. (For some further discussion of fire control computers using electrical or electronic elements, see chapter 5.)

A digital computer essentially performs the basic arithmetical processes—addition, subtraction, multiplication, and division—by counting. The ordinary office calculating machine is a mechanical digital computer.

An analog computer represents mathematical relationships by analogous mechanical motions and positions. These may vary from moment to moment by large or small amounts, but the solution is produced continuously. Its output at any given instant measures the values at that instant of the two or more changing quantities in the problem it has been designed to solve. A simple example will help to make this clearer. Suppose the hypotenuse of a right triangle remains constant in value but the two acute angles are continuously changing. One of the computing devices described later in this section will tell the operator (or the related computing mechanism) the exact values of the base and altitude of this triangle, whenever these values are needed in the solution of a larger problem.

For solving the fire control problem, the mechanical analog computer is much faster than any combination of mechanical digital units. It is not as versatile as a digital computer, but a fire control computer is required to deal only with fire control problems. The fact that it is not adapted to other problems is not a drawback.

The following tabulation lists some of the shipboard computing devices (usually mechanical or electromechanical analog types) that a junior officer is likely to encounter. In gun systems:

- Fire control computers
- Gun directors
- Gun elevation indicators
- Gun train indicators
- Parallax correctors
- Rangefinders
- Rangekeepers
- Receiver-regulators
- Sightsetter's indicators
- Stable elements
- Stable verticals
- Star-shell computers
- Wind transmitters

In torpedo and ASW systems:

- Course directors
- Depth computers
- Attack directors
- Range recorders

Later chapters will explain the functioning of many of these computing devices. The paragraphs following will take up a number of their representative mechanical components and tell briefly how they work.

ADDING AND SUBTRACTING DEVICES. As was explained earlier, the output of a differential (figs. 3B14, 3B15, 3B16) measures the sum or the difference of two inputs.

Finely constructed mechanisms with light loads sometimes use a compact jewel differential that has spur gears instead of bevel gears. The operating principle is exactly the same as in the bevel type.

A shaft can be designed to add some selected constant to the value it would normally transmit. Figure 3B18 shows a two-shaft combination arranged to transmit an output of range-minus-50.

Each shaft in figure 3B18 has a mechanical counter showing its output. In the first view, the two shafts have been zeroed, coupled, and turned as a unit until the output of each is 50 yards.

In the center view, the crankshaft remains clamped to the sleeve coupling, but the input shaft has been unclamped and reset at zero. When the loose clamp is tightened again and the two shafts turn as one, the variable introduced

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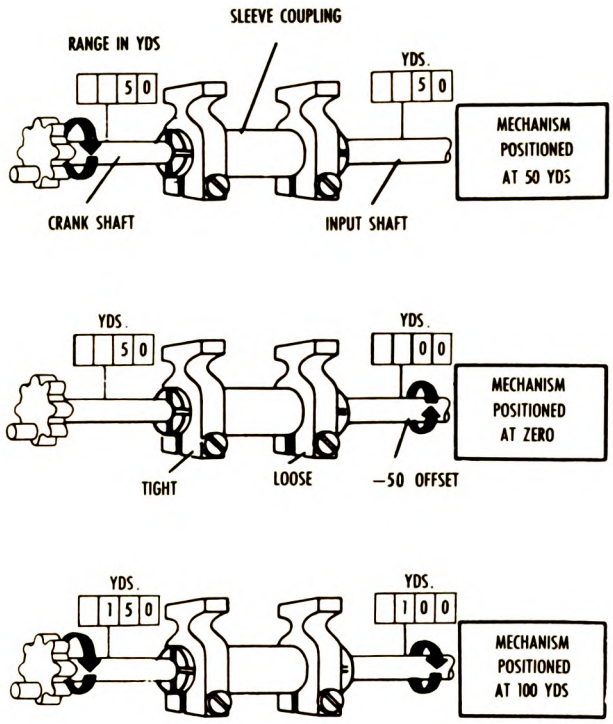

110.11

Figure 3B18.—A coupling used to introduce a constant.

5.29

Figure 3B19.—Some representative computing cams.

by the crankshaft will be reduced by 50 when the input shaft transmits it. For example, in the lower view, a crankshaft reading of 150 yards is transmitted by the input shaft as 100 yards.

This use of a sleeve coupling is called "putting a constant offset on the line." The offset can be either negative, as here, or positive.

CAMS, MULTIPLIERS, AND DIVIDERS. The use of shafting and gearing in solving problems in ratio and proportion has already been explained, and it is an extremely important use.

By the use of cams, quantities that vary according to other laws can frequently be introduced into the gearing, either for transmission to a dial or for further use in solving the problem.

A great many mathematical relationships can be expressed, accurately and compactly, as graphs on squared paper. It is possible to construct cams that reproduce these graphs. The spiral cam in figure 3B17 is only one of a great variety of possible types. Three commonly used cams are shown in figure 3B19.

In computing cams, such as the three shown in figure 3B19, the output is a function of the input; that is, it varies with the input, but not in direct proportion. The output of the reciprocal cam is one-divided-by the input. The input of the secant cam is the value of a given angle; the output is the secant of that angle. Cams can, of course, be cut to represent other trigonometric functions. The square cam multiplies the input by itself. The subject of cams is much broader and more complex than this necessarily limited paragraph would indicate.

Sometimes cams cannot be designed to show the output values for all possible inputs; but they can still be used to take care of inputs within certain ranges that are adequate for the needs of the system.

The SCREW-TYPE MULTIPLIER shown in figure 3B20 is a device that computes, continuously and accurately, the product of two continuously changing input values. Actually there

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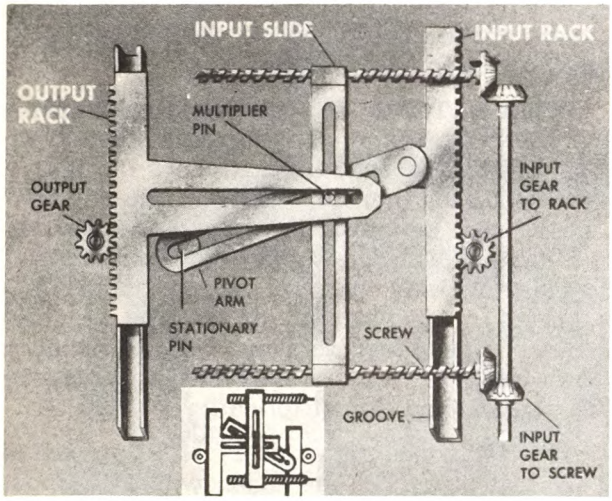

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Figure 3B20.—A screw-type multiplier.

are several types of multipliers, but all of them make use of the laws of proportion as exemplified by a pair of similar triangles.

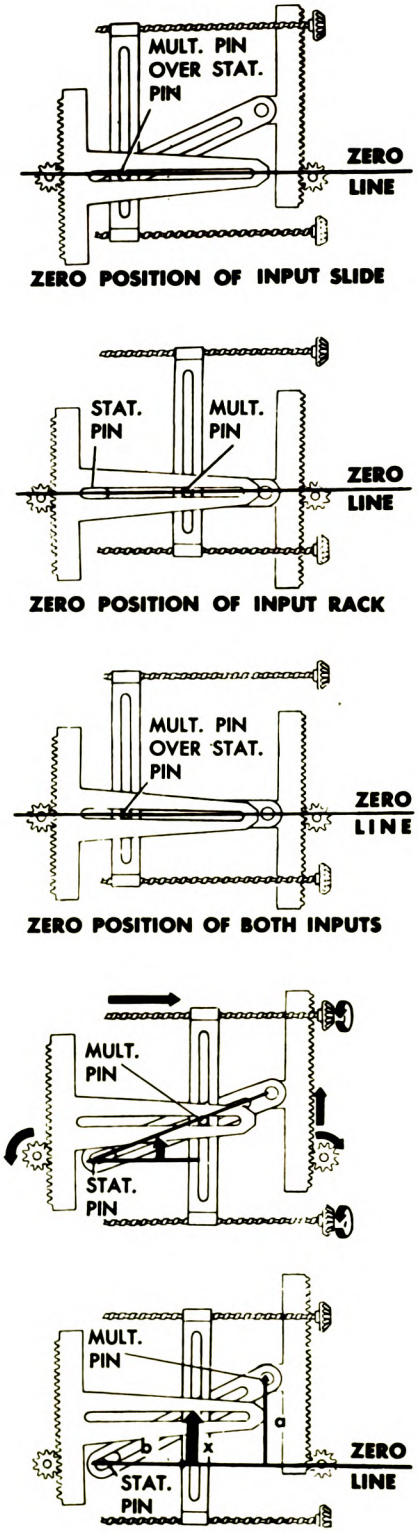
The multiplier illustrated here receives one of its inputs through a slotted slide that is walked out from (or back toward) its zero position by two screws that are turned by bevel gears. The second input enters through a slotted arm that pivots on a stationary pin, and is joined at its opposite end to an input rack.

In its zero position, the pivot arm is perpendicular to the input slide. The pivot arm is forced away from (or back toward) its zero position whenever the input rack is moved by the input spur gear.

A multiplier pin passes through the slots in the input slide and the pivot arm. This pin also passes through a third slotted member—the T-shaped output rack.

Whenever the input to the slide, the input rack, or both is zero, the multiplier pin will lie at some point along the zero line shown in figure 3B21. The slot in the output rack will also lie along the zero line. This is correct, since any quantity multiplied by zero equals zero.

Whenever the input slide and the input rack BOTH move from their respective zero positions, the multiplier pin will be above the zero line by a vertical distance that, as will be shown in the next paragraph, measures the product of the two inputs. The output rack will be displaced



12.92

Figure 3B21.—How the multiplier works.

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by this same amount, and will transmit the measured product as its output.

Figure 3B22 shows how this particular multiplier utilizes geometric truths. In this figure, the constant K is the distance, along the zero line, from the stationary pin to the vertical line of travel of the right end of the pivot arm. Solid line a is the distance the input rack has moved from zero. Dotted line b is the distance the input slide has moved to the right of zero. Dotted line x is the distance the multiplier pin and, with it, the input rack has moved up from zero.

Notice that these relationships define two similar right triangles, one superimposed on the other. Since the corresponding sides of similar triangles are in proportion,

$$\frac{x}{a} = \frac{b}{K}$$

and

$$x = \frac{ab}{K}$$

That is, x which represents the output, is the product of the two inputs, divided by a constant. A proper choice of gearing ratios can remove the effect of the constant.

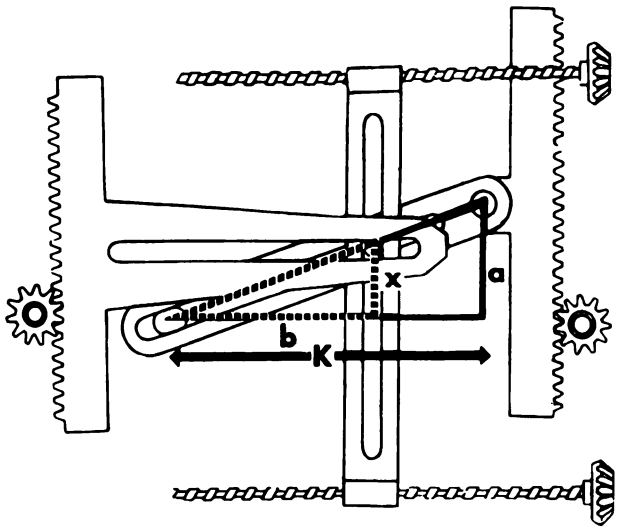

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Figure 3B22.—Similar triangles in the multiplier.

In actual practice, to save space, a multiplier is often designed to deliver a fixed fraction (say a tenth) of the whole product. Gearing converts this fraction to the full value.

INTEGRATORS. In some phases of the broad fire control problem—and in many other situations as well—a quantity that obeys the laws of proportion (and therefore can be transmitted by a gear) must be multiplied by a second quantity that varies at a constantly changing rate of change. We say that the second quantity accelerates, or decelerates, or changes by increments. The integrator, one type of which is shown in figure 3B23, is a device that performs this special kind of multiplication.

The horizontal disc is driven at a constant speed that measures the non-accelerating input. A gear-and-rack arrangement receives the accelerating or decelerating input and uses this input to drive a movable carriage backward or forward along a selected diameter of the disc. The carriage contains two balls, one directly above the other, that are free to turn.

Except when it is above the dead center (zero point) of the disc, the lower ball rotates whenever the disc turns. The speed of the ball depends on two factors—the constant speed of the disc itself and the variable point at which the carriage is positioned at the given instant. The nearer the ball is to one edge or the other of the disc, the faster it will rotate.

The lower ball drives the upper ball. (The designer uses a pair because the two balls roll more smoothly than a single one. In other designs a single ball or a roller can be used.) The rate of rotation of the balls measures the product of the non-accelerating input and the accelerating input. The upper ball drives a roller which, in turn, transmits its constantly varying output to the next stage of the gearing system.

At one side of the center of the disc, the balls transmit positive values; at the opposite side, negative values.

COMPONENT SOLVERS. A vector is a line drawn to show both the direction and the magnitude of a force. Such quantities as target speed and wind motion are shown on graphs as vectors. For practical purposes, a vector can be treated as the diagonal of a rectangle that has one corner at the zero point of a conventional graph, one side along the x-axis, and one side along the y-axis. These sides of the rectangle represent the two components that make up the vector.

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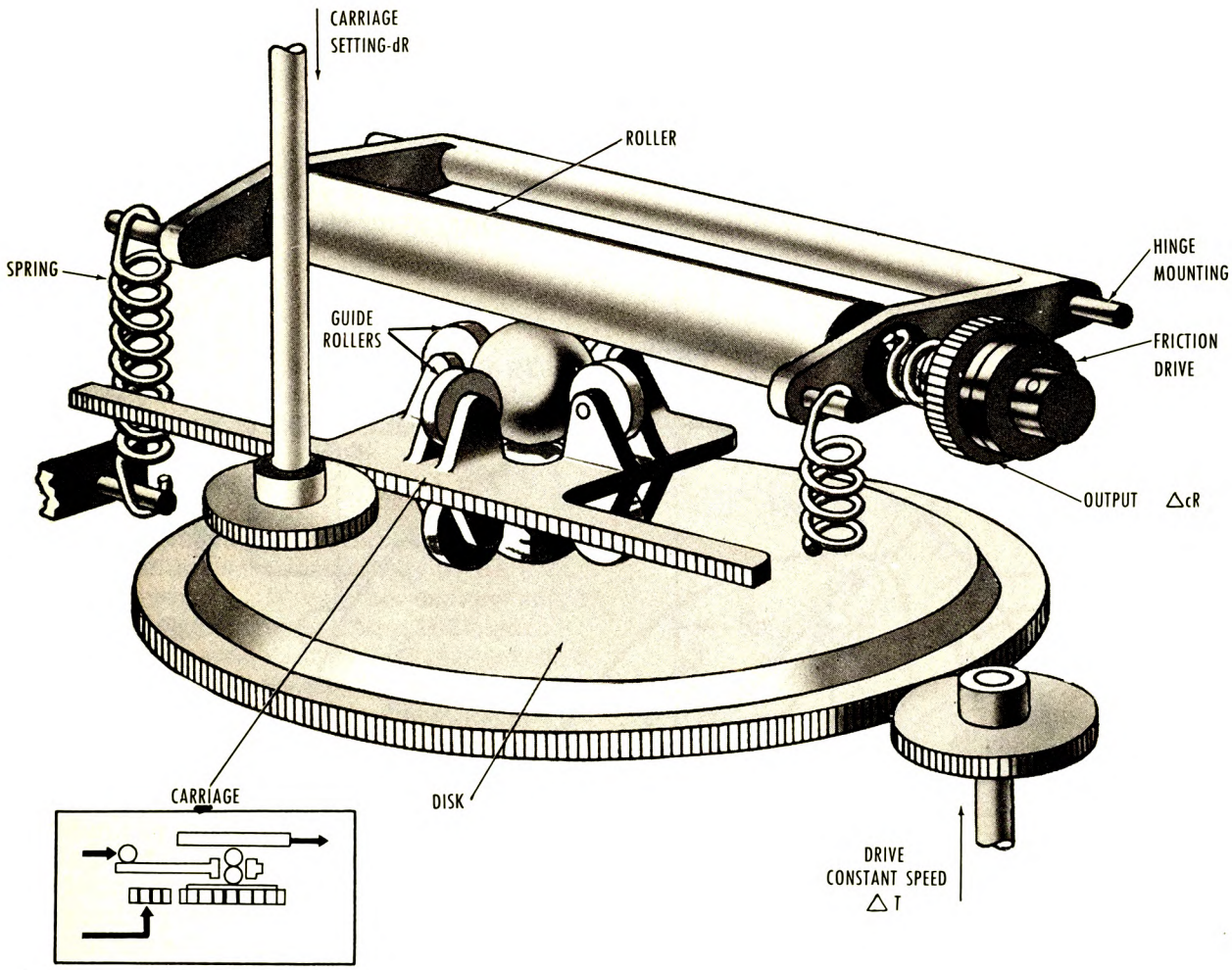

110.12

Figure 3B23.—A disc-type integrator.

The two components can be computed by simple trigonometric methods. When it is desirable to perform this operation automatically, a component solver computes the desired values and transmits them.

Figure 3B24 shows the operating principle (but not all the structural details) of a typical component solver. The dial carrying the compass rose and own-ship outline can be rotated about the zero point of the graph. This dial is set at an angle representing the relative target bearing (angular offset of own ship's centerline from the line of sight). The vertical pin is positioned at a distance from center that represents own ship's speed. Thus the vector is established.

Two L-shaped slides, arranged as shown in the illustration, are slotted to receive camming action from the vertical pin. The slides move whenever the pin moves, but they are so mounted that the range slide always moves parallel to the line of sight and the deflection slide always moves perpendicular to the line of sight. The distances travelled by the two slides always measure the values Xo and Yo, which are the two quantities this particular component solver is designed to transmit.

A mechanical component solver can resolve a vector rapidly; but a wire-wound resolver, constructed on the principles of the synchro, can receive an input that measures the vector and

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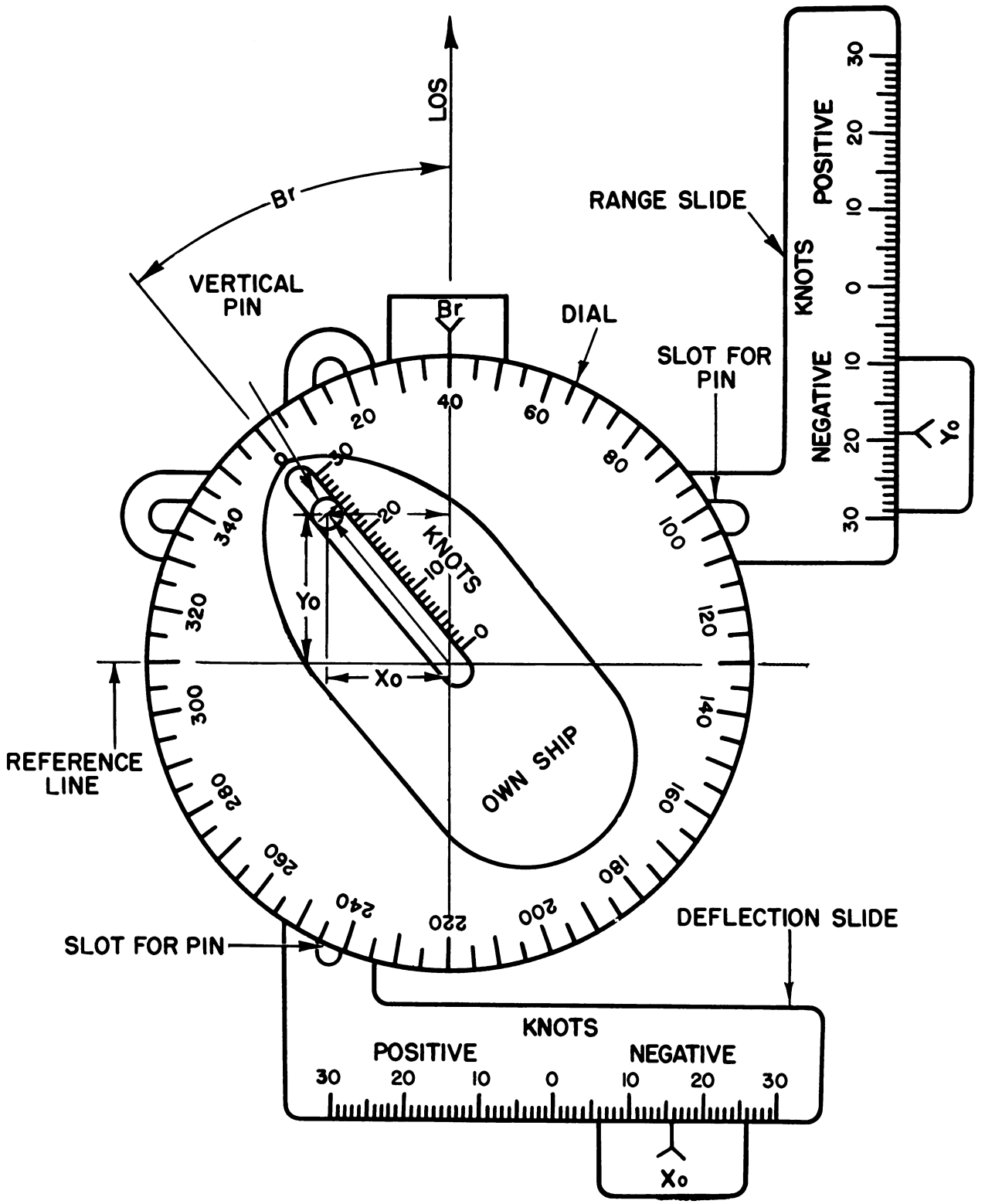

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Figure 3B24.—The principle of the component solver.

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instantaneously transmit a pair of outputs that measure the components.

NOTE: In addition to elaborate gearing and shafting, and also in addition to a large number of electrical devices, the Mark 1 computer, a World War II design, contained 9 component solvers, 10 integrators (representing two types) 15 multipliers (both simple and complex types) 8 cams, 24 handcranks, and more than 150 differentials.

3B4. GYROSCOPES

A gyroscope (colloquially called a gyro) is fundamentally a rapidly spinning wheel. Its rotational momentum gives it two useful properties:

1. rigidity in space
2. precession

The first property was mentioned in article 3A2 as caused in any rotating body by its rotational momentum. It can be demonstrated easily in a toy gyroscope (figure 3B25, part A) which, when spinning rapidly and supported at one end, will appear to defy the law of gravity by remaining horizontal while the other end is unsupported.

At the same time, though, the gyro will demonstrate the effect of the second property, precession, by rotation in a horizontal plane about its point of support, as shown in part B of figure 3B25. Gravity pulls the unsupported end of the spinning gyro wheel's axle vertically downward. But the axle doesn't move downward; instead it reacts by moving horizontally (i.e., at 90° to the pull of gravity).

To understand precession, consider the spinning mass of the large wheel shown in figure 3B26. An applied force symbolized by thick arrows labeled APPLIED FORCE (at the top and bottom of the wheel's axle) tends to tip the axle (i.e., rotate it about the axis Y-Y). Particle A is part of the spinning wheel's rim. At some instant its inertia is moving it in the direction AC. But the applied force tends to move it in the direction AB. It cannot move in two directions at once. It responds to the two forces acting simultaneously upon it by moving in the direction AD. But to do this the wheel's plane of rotation must shift as shown in the smaller diagram in figure 3B26. If the wheel's plane of rotation shifts, so does its axis of rotation (X-X). This shift is at an angle of 90° to the axis of the applied force (Y-Y). By turning figure 3B26 on its side and comparing it with figure 3B25, part B, you can

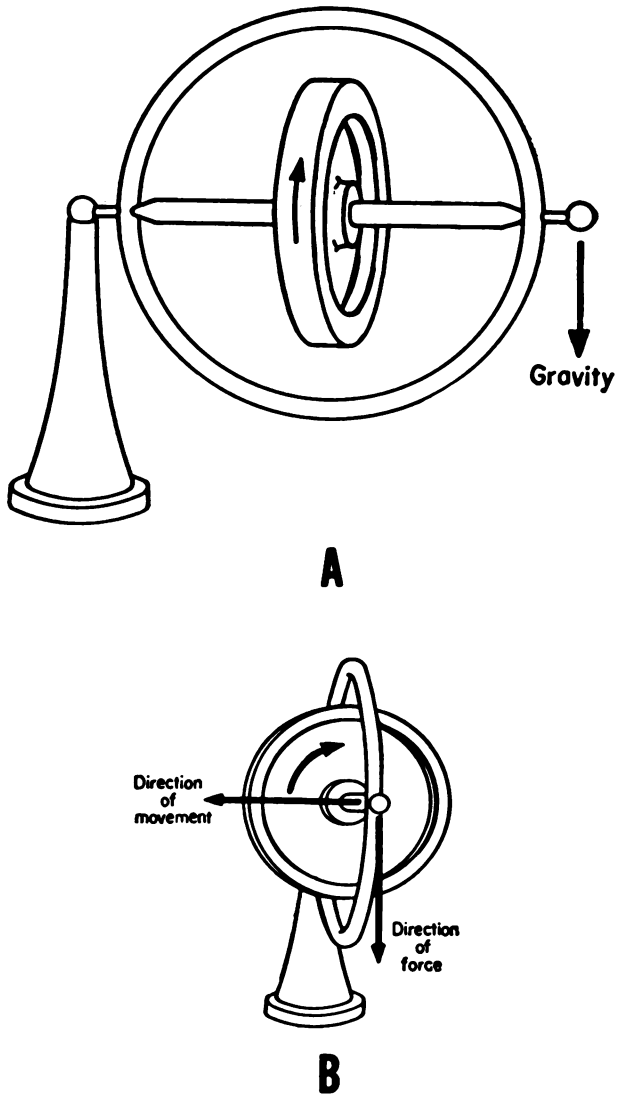

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Figure 3B25.—Elementary gyro action.
A. Rigidity in space; B. Precession.

see how the force of gravity pulling the axle downward can cause the axle to move horizontally.

The gyro's first property (rigidity in space) makes it desirable to use for establishing a reference direction (as in a torpedo or gyrocompass) or a reference plane (as in a stable element). In these applications the gyro wheel is so mounted that it will not be affected by changes in the direction of the vehicle that carries it. Since

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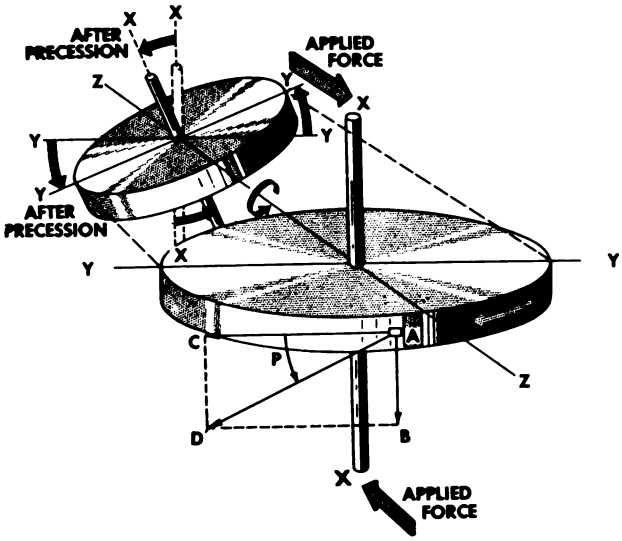

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Figure 3B26.—Gyro precession.

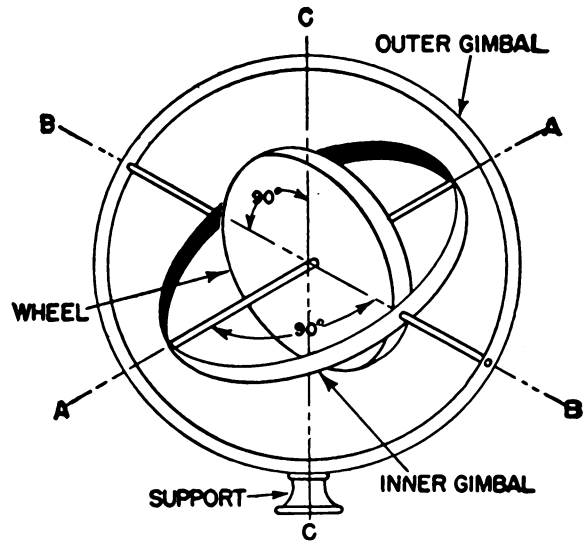

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Figure 3B27.—The principle of gyro mounting.

the precessional force is related to the deflecting force applied to the gyro, its second property (precession) is used (in lead-computing fire control equipment) when it is necessary to determine the amount of lead required for a gun projectile to hit a moving target. These applications are discussed in later chapters of this course.

In these applications, it is necessary to mount the gyro wheel with the amount of freedom required in each case. This is done by using gimbals. A gimbal is a metal ring (or part of a ring) supported so that it can rotate about an axis formed by two points 180° apart on its circumference. Figure 3B27 shows a gyro wheel supported in two gimbals so that it has three degrees of freedom.

The gyro rotor is free to spin on its axis A-A. That's one degree of freedom. The rotor axis is supported in bearings in the inner gimbal ring, which is free to turn on the axis B-B. That makes two degrees of freedom. The outer gimbal, pivoted on the support, is free to turn on axis C-C. That gives the gyro its third degree of freedom. With three degrees of freedom, the gyro can maintain its rigidity in space no matter how its support moves.

C. Principles and Applications of Hydraulics

3C1. INTRODUCTION

DEFINITIONS. Fluids are materials that continuously adapt their shape to fit their containers. Fluids include both liquids and gases. In this section the main emphasis will be on liquids.

Hydraulics, in the strict sense, deals with the behavior of liquids in motion through a closed (that is, liquid-filled) system of connected containers. In its practical applications, hydraulics is concerned with the uses of fluid-filled systems in transmitting applied forces and producing or controlling mechanical motion.

A closely related science, called hydrostatics, deals with the behavior (including especially the pressure aspects) of fluids at rest in open containers. These may be such large "containers" as lake or ocean beds. In actual practice, the Navy man ordinarily expands hydraulics to include hydrostatics.

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HYDROSTATIC PRESSURE. Any liquid in an open container exerts pressure equally in all directions from any given point within the liquid. The degree of pressure on a submerged object varies directly with the depth the object has reached. At a depth of one foot in sea water, the bottom of a mine case is under hydrostatic pressure of 64.3 pounds for each square foot of its surface. At a 10-foot depth, the pressure is 10 times as great, or 643 pounds per square foot.

Underwater weapons—particularly mines and many depth charges—have various components that remain inactive until the hydrostatic pressure on the exterior of the device becomes great enough to overcome a built-in resistance, such as that offered by a spring or an expanded bellows.

APPLIED PRESSURE. A liquid in a closed system also exerts hydrostatic pressure, but this is not a major consideration in any component except the storage reservoir. This reservoir must contain enough liquid (and exert enough pressure or head) to keep all the enclosed spaces filled during a complete cycle of operation.

The really important fact about pressure in a closed system is the capacity of the liquid for transmitting—rapidly and in all directions—a force that is applied to one component of the system. Because it can do this, an enclosed liquid can be used, much as a basic machine is used, to overcome resistances and move loads.

BASIC PRESSURE-MOTION RELATIONSHIP. The system shown in figure 3C1 is not equipped to produce a work output that has any practical value outside the classroom. It does, however, have teaching value in that it shows the basic principle behind many more elaborate and highly practical systems.

In figure 3C1 a total downward force of 25 pounds is applied to the small piston, whose head has an area of 5 square inches. The pressure applied through this piston to the enclosed liquid is 25 pounds for each 5-square-inch area of container surface. The unit pressure is, therefore, 25/5 or 5 pounds per square inch. (This unit pressure may be abbreviated 5 psi; the letter symbol is pronounced p-s-i, not like the name of the Greek letter Psi.)

The input, transmitted equally in all directions throughout the liquid, acts on the large piston head with an upward pressure of 5 psi. The large piston head has an area of 250 square inches. It is, therefore, subjected to a total upward force of 250 X 5, or 1250 pounds.

The system is similar, in effect, to a lever in which E is 25, R is 1250, and the theoretical

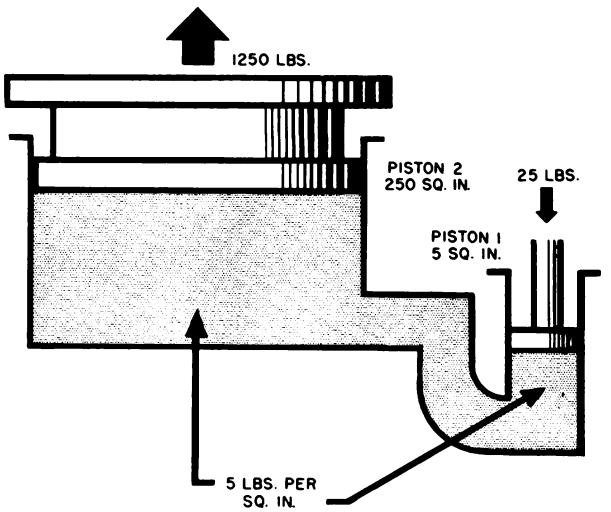

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Figure 3C1.—The basic principle of hydraulic pressure.

mechanical advantage is 50. But, just as in the lever, the distances travelled by the effort and the resistance are in inverse proportion.

For example, if the small piston moves downward an inch, it displaces 5 cubic inches of practically incompressible liquid that must be accommodated somewhere unless the system is to burst. The large piston is the only component that can move to make room for the displaced liquid; but it needs to move upward only 5/250 or 1/50 inch to accommodate the 5 cubic inches of fluid.

This system lacks some of the essential components of a useful hydraulic mechanism. The next article will mention and briefly explain those components.

3C2. SYSTEM COMPONENTS

FLUID RESERVOIR. Because certain working members of a hydraulic system move up and down or in and out, the amount of space inside the system varies. To keep the available space filled at all times, the system must have a storage tank or reservoir to accommodate back-up fluid and return it to the system as needed. The depth (or the elevation, which amounts to the same thing) of the storage reservoir must be designed to furnish enough hydrostatic pressure or head to keep all enclosed areas filled during a complete cycle of operation.

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PISTONS AND CYLINDERS. Figure 3C1 shows elementary examples of the working parts present, in one form or another, in all hydraulic mechanisms. These are the cylinders that accommodate varying amounts of fluid and the pistons (short, closely fitted interior cylinders) that move, in response to mechanical or hydraulic pressure.

Usually the piston is attached to a rod that projects through a leakproof opening in the capped end of the enclosing cylinder. The usual purpose of the rod is to receive a mechanical input or to transmit an output.

CONNECTING LINES. The system must have connecting lines joining the working components to one another and to the reservoir. These lines, like the one connecting the two cylinders in figure 3C1, may sometimes be part of a single casting. If the working elements are a distance apart, pipes are used to connect them.

VALVES. A workable hydraulic system must have valves that open and close to keep the fluid moving in the right direction, in the right amounts and at the proper pressure. The valves must also prevent the liquid from moving away from certain areas until it has accomplished its work. A lack of valves robs the device in figure 3C1 of practical value.

There are many types of valves, varying from extremely simple to fairly complex designs. Some have stems that permit an operator to admit fluid, to cut it off, or to allow flow at a reduced rate. Others are operated by the internal pressures that develop within the system. At this time only a few valves of the simpler sort will be considered.

The COCK is a plug-type valve permanently seated within a pipe. A cylindrical opening in the plug can be turned at will, to permit flow or to block it. Figure 3C2 shows the top view of a typical cock.

A GATE VALVE, like a cock, can be turned by an operator to admit or obstruct flow. Instead of staying within the pipe in its open condition, the gate valve occupies a projecting "bonnet," as shown in figure 3C3.

A NEEDLE valve has a tapered point to permit gradual opening or closing in an area where a more sudden change of pressure would be dangerous.

A CHECK valve, responding automatically to pressure changes within the system, opens to permit flow in one direction and closes to check or prevent flow in the opposite direction. Spring or gravity action sometimes hastens the closure of this valve. Figure 3C4 shows a check valve hinged at the top to allow flow toward the right and prevent flow toward the left. A check valve is sometimes called a directional valve.

A SAFETY or a RELIEF valve (the two types are similar but not identical) is a spring-loaded check valve that keeps an exhaust or bleeder pipe closed until an excessively high pressure within the main line overcomes the built-in spring resistance and opens the valve.

SPOOL valves and ROTARY valves may, depending on design details, be operated by hydraulic or electrical actuators, or may (less frequently) be hand-operated. These valves are used in more complex hydraulic systems to direct fluid flow as desired for system operation.

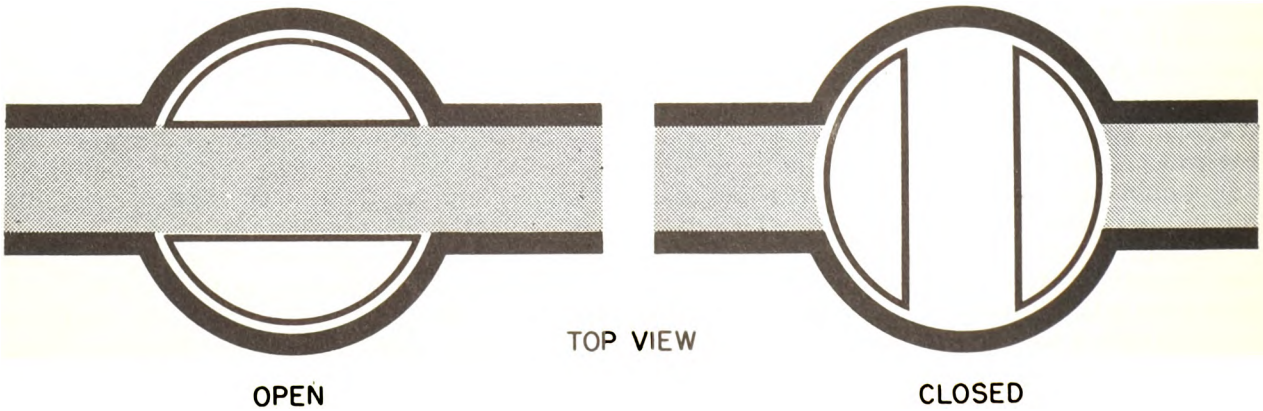

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Figure 3C2.—How a cock controls flow.

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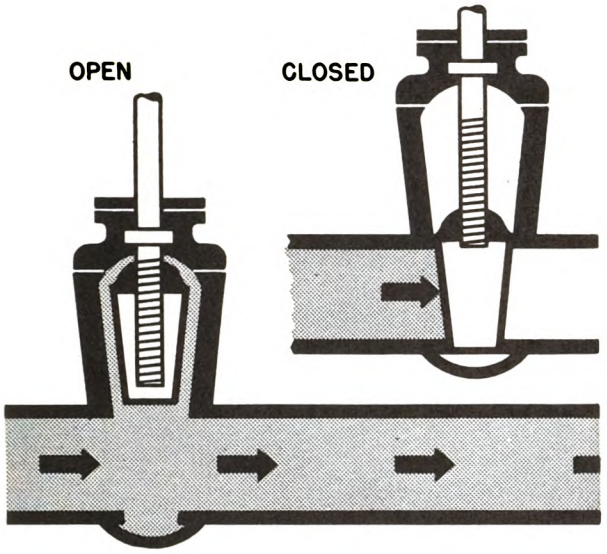


110.16

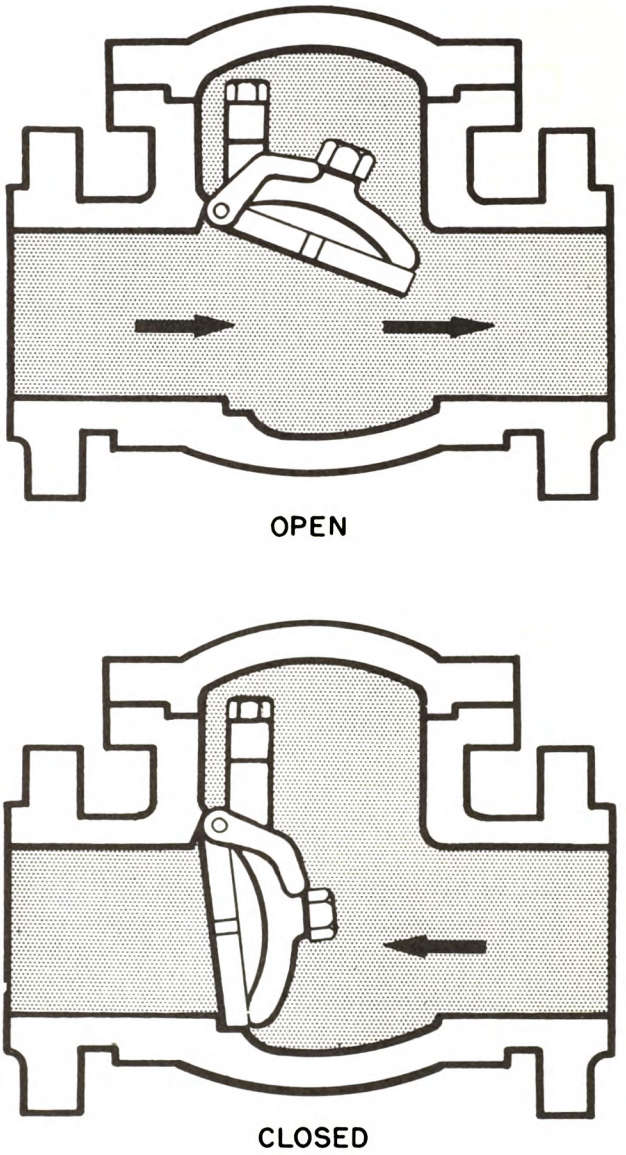
Figure 3C3.—How a gate valve opens.

SIMPLE PRACTICAL APPLICATION. Before taking up the pump, the reader may be interested to see that the addition of devices described thus far—a storage reservoir, a connecting line, two check valves, and a gate valve—can turn the device shown in figure 3C1 into the highly useful hydraulic jack shown in figure 3C5 and, somewhat later, in figure 3C6.

The valves numbered 1 and 2 in the illustration are check valves. Valve 1 is hinged at its left-hand side. It is open because fluid under pressure has been forced against its lower face by the down stroke of the small piston. When open, this valve admits displaced fluid to the large cylinder. Valve 1 cannot swing downward beyond its horizontal or closed position.

Valve 2, shown closed in figure 3C5, is hinged at the top. It opens by swinging toward the small cylinder. It cannot swing open in the direction of the storage tank. This valve is closed by the pressure exerted during the down stroke of the input piston, for this applied pressure exceeds the hydrostatic pressure exerted on the opposite face of the valve by the liquid in the storage tank.

Valve 3, the GATE valve, is kept closed while the operator is using the jack to lift a load. Acting as a pair, valves 1 and 3 keep the displaced fluid trapped in the large cylinder. Upon completion of his work, the operator opens valve 3, thus allowing the displaced fluid to return to the reservoir as the large piston sinks by gravity to its normal position.



33.50

Figure 3C4.—The operating principle of the check valve.

Figure 3C6 shows the relationships within the jack during the up stroke of the input piston. As this piston is pulled upward, the pressure within the small cylinder drops, and a partial vacuum is formed. The hydrostatic pressure of the fluid in the storage tank forces valve 2 open

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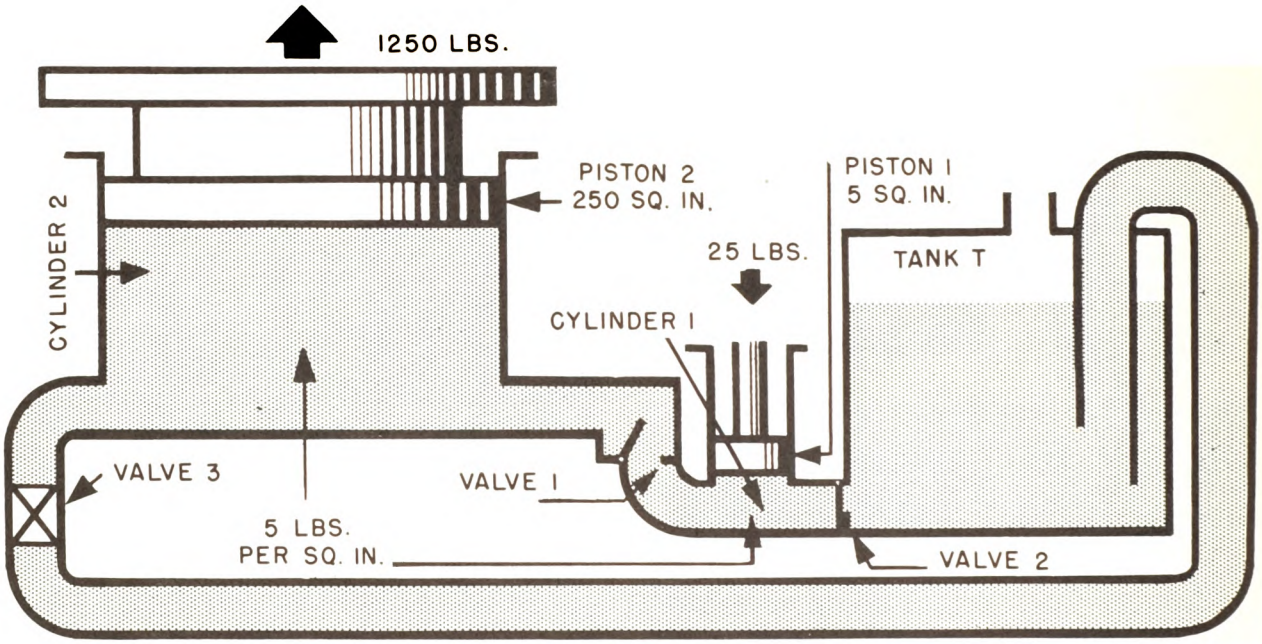
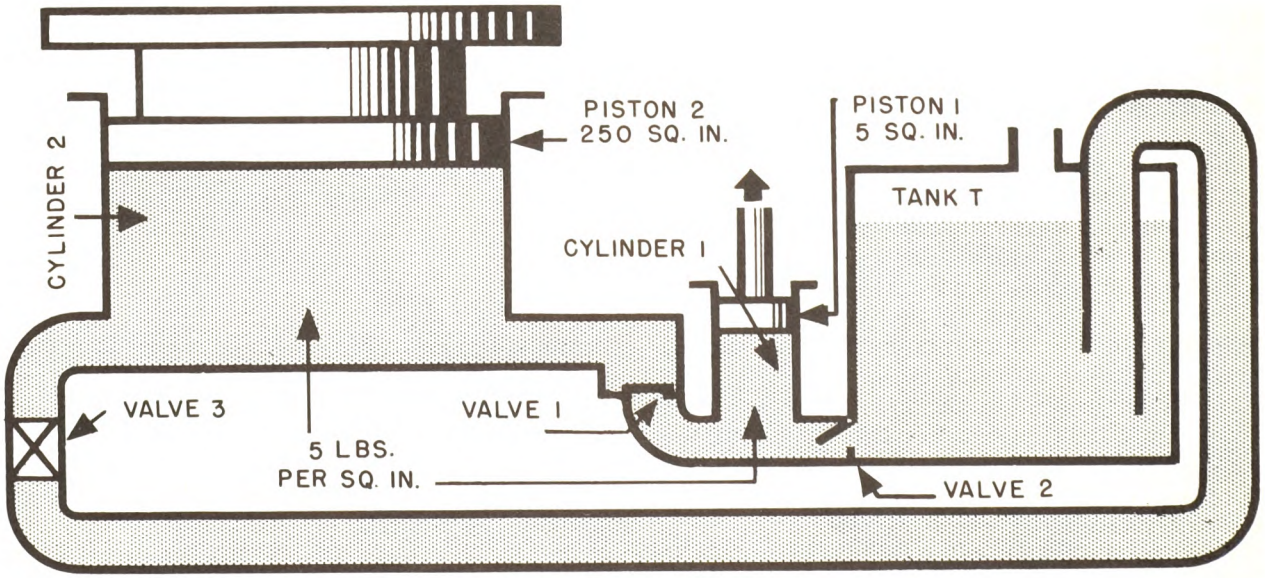


110.17

Figure 3C5.—A hydraulic jack—down stroke of the input piston.



110.18

Figure 3C6.—A hydraulic jack—up stroke of the input piston.

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and lets fluid enter the small cylinder as long as the piston is rising.

Because the pressure in the small cylinder has dropped below that in the large cylinder, the large piston tries to drop and restore balance; in technical language, the large piston exerts back pressure, forcing valve 1 downward to its horizontal or closed position. Because this valve cannot swing below the horizontal, it simply remains closed until it is opened (and valve 2 is closed) by the next input stroke.

The cycle shown in figures 3C5 and 3C6 is repeated until the liquid trapped in the large piston has lifted the load as high as the operator wishes, within the capabilities of the jack.

THE SIMPLE PUMP. A pump is a mechanism that uses an external source of power to apply force to a fluid. All pumps in open hydraulic systems take advantage of the fact that the earth's atmosphere, a gaseous fluid, exerts a static pressure whose existence becomes noticeable whenever a partial vacuum is created.

Anybody who drinks through a straw is making use of this phenomenon. By sucking on the straw, he creates a partial vacuum. Atmospheric pressure, acting on the liquid in the tumbler, forces enough of it up the straw to dispel the partial vacuum.

In a common hand pump, figure 3C7, the lever-type pump handle is joined to a piston rod with a simple upward-opening check valve (numbered 1) in the piston. The downstroke of the piston applies pressure to the water in the pump, opening valve 1 and closing another check valve (numbered 2) at the base of the pump.

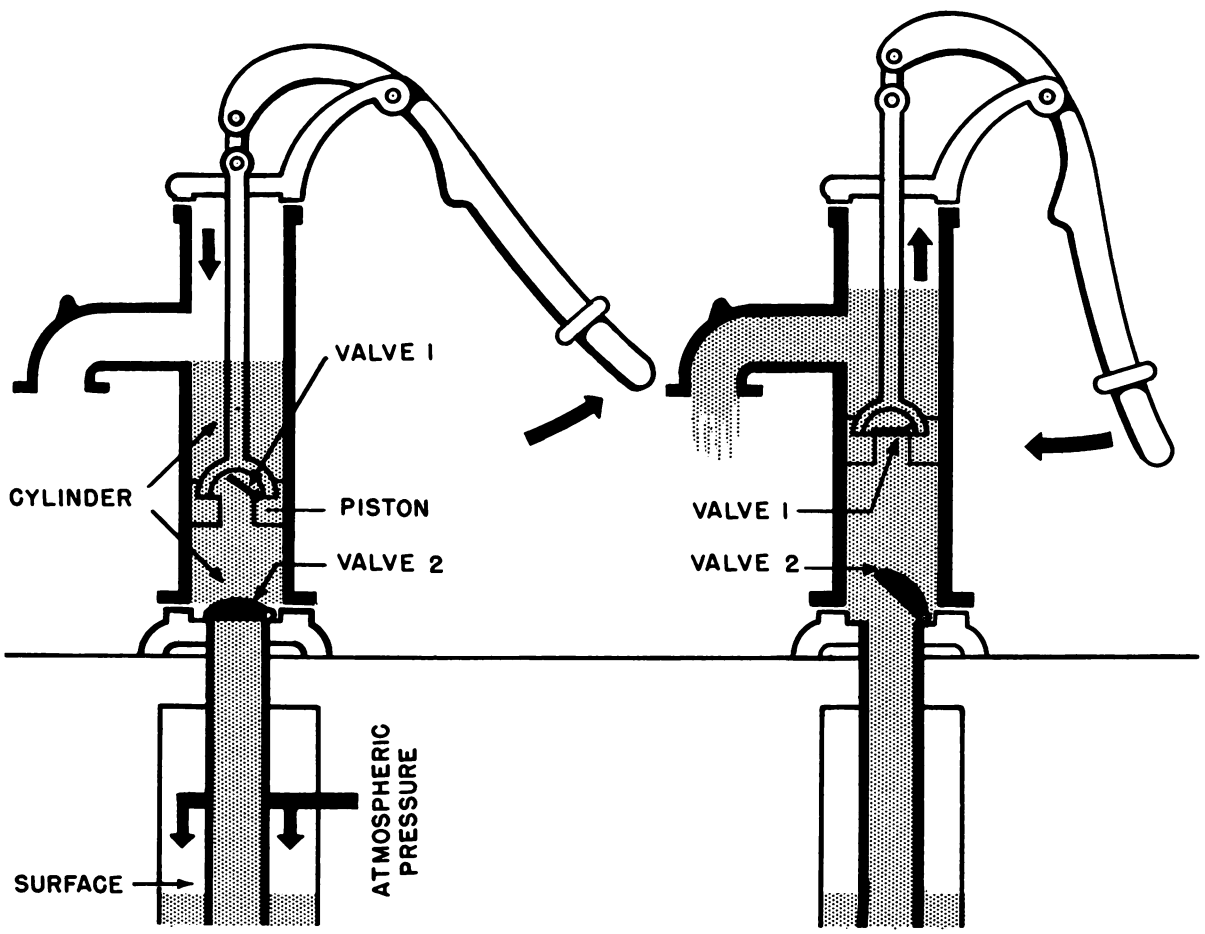

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Figure 3C7.—How a simple hand pump operates.

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On the up stroke of the piston, pressure is reduced, and a partial vacuum is created, in the area between the two valves. Valve 1 closes. Atmospheric pressure in the well forces water up the pipe. The upward thrust of the water opens valve 2 but is not strong enough to open valve 1 as long as the piston continues to rise. The excess water thus drawn into the pump flows from the spout.

There is a great difference in structure, though not in fundamental operating principle, between the simple hand pump in figure 3C7 and the Waterbury constant-speed, axial-piston, variable-delivery pump that constitutes the A-end of a gun's electric-hydraulic train or elevation power drive. The summary below will prepare the way for the description of the A-end in article 3C3.

SOME FACTS ABOUT PUMPS. Pumps that are designed to perform work operations are installed as integral parts of closed hydraulic systems in which fluid from a reservoir is repeatedly circulated by pump action. These pumps are divided into two main classes—the reciprocating and the rotary type.

RECIPROCATING pumps deliver liquid by a back-and-forth movement of mechanical parts. ROTARY pumps deliver liquid by a circular (or other curved) motion of mechanical parts. The A-end is a reciprocating pump. The following numbered statements apply to it.

1. By lengthening or shortening the work stroke of its piston(s), a reciprocating pump can be made to deliver a larger or smaller volume of liquid per stroke.

2. Reciprocating pumps can be constructed to utilize two, three, or even many piston-and-cylinder units arranged in a cylinder block and driven by an ordinary power motor.

3. An AXIAL-PISTON reciprocating pump has a cylinder block that rotates on a central shaft in such a way that the pistons move back and forth in a direction parallel to the shaft.

4. A VARIABLE-DELIVERY axial-piston pump contains a means of varying the piston stroke (and thereby varying the output of the pump) automatically in response to control signals.

ACCUMULATORS. An enclosed hydraulic system usually contains an accumulator that stores a certain amount of fluid under air pressure. When there is a sudden heavy demand for fluid, in excess of the capacity of the pumps, fluid from the accumulator enters the system and tends to equalize the flow.

3C3. ORDNANCE HYDRAULIC MECHANISMS

This article will take up, in rather general terms and without fine details, some of the hydraulic devices that are found associated with gun mounts, turrets, and missile-launching systems. Because the way has already been prepared for it, the hydraulic pump or A-end will be described first.

HOW THE A-END WORKS. Instead of having a single piston like the ordinary hand pump, the A-end often has nine piston rods, each with its own cylinder. These cylinders are arranged in a cylinder barrel that rotates in a fixed plane perpendicular to its central shaft.

The ends of the cylinders are joined to a socket ring that rotates with the cylinder barrel but at the same time tilts at an angle that can be varied from 20° on one side of the position of zero tilt to 20° on the other side. A universal joint, similar in principle to the one shown in figure 3B4, allows the socket ring to be driven and tilted simultaneously. The amount and direction of tilt depend on the control signal the A-end receives.

The simplified drawing in figure 3C8 shows one possible angle of tilt between the cylinder barrel and the socket ring. The yoke-like structure in which the socket ring is bearing-mounted is called the tilt box. The ring is tilted in accordance with signals from the indicator-regulator.

When the A-end is in operation, the cylinder barrel rotates in the vertical plane, and the socket ring rotates with it, at an angle determined by the input signal. Unless the cylinder barrel and the socket ring are exactly parallel, each piston rod, during a complete cycle, will be pushed into its cylinder (thus increasing the internal pressure) for a half-cycle and then will be drawn toward the opposite end of the cylinder (thus reducing the internal pressure) for the next half-cycle. The cylinder barrel as a whole will have a high-pressure side and a low-pressure side.

To get pumping action, then, it is only necessary to arrange pipe lines and valve ports in such a way that hydraulic fluid can always be drawn into the cylinders as the internal pressure decreases and can always be forced out as the pressure increases. The valve plate shown in figure 3C9 makes the necessary arrangements.

To minimize leakage, the rotating cylinder barrel bears closely against the fixed valve plate at all times. For the angle of tilt shown in figure 3C9, the lower pipe line is the intake and the

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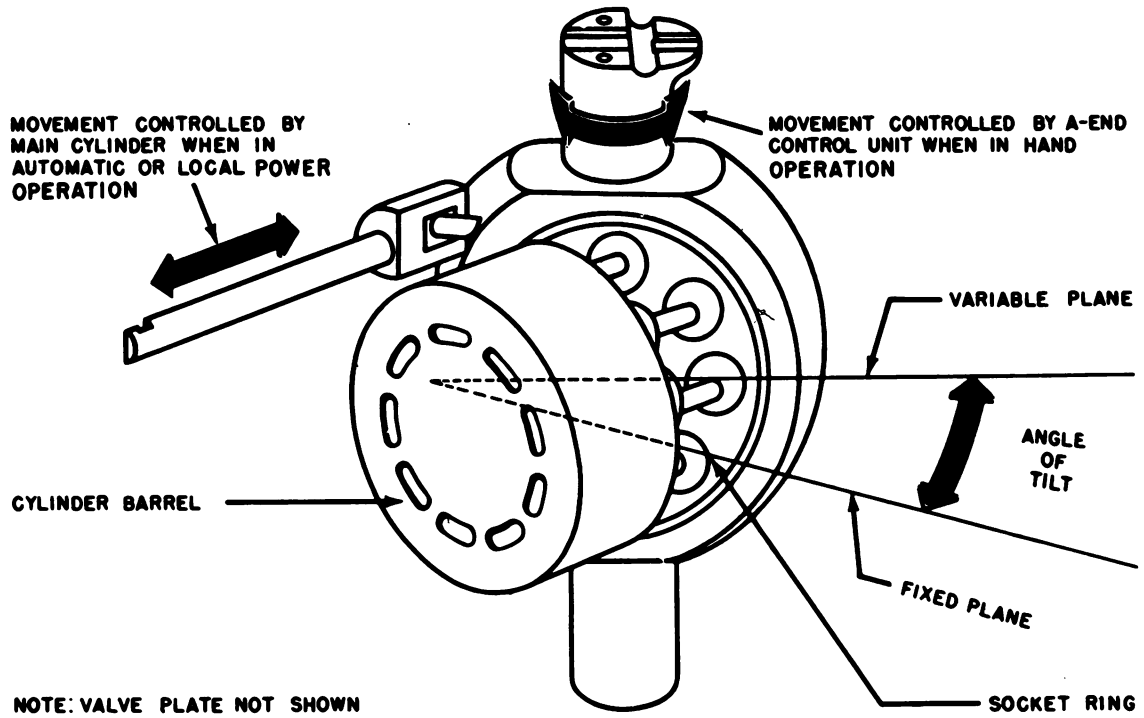

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Figure 3C8.—Angle of tilt in the A-end.

upper line is the output. Lands, corresponding to the neutral-pressure (9 o'clock and 3 o'clock) positions of the cylinders (figure 3C9, part A) prevents short-circuiting of the two sides. When the angle of tilt reverses, the high-pressure side becomes the low-pressure one, and the direction of flow reverses. Figure 3C9, part B, shows the assembly in phantom.

In some installations, the B-end or hydraulic motor is separated from the A-end as shown in figure 3C10. In others, the B-end is directly connected to the valve plate. In either event, the action of the two ends is the same.

B-END. The B-end, shown as a phantom in figure 3C11, is much like the A-end in design, except that the angle of tilt is built in and cannot be changed. The valve ports on the intake side receive oil under pump pressure from the A-end. This oil exerts forces at right angles to the faces of the pistons open to the intake ports. These forces can each be broken into two components—(1) a thrust component along the axis of rotation that serves no useful purpose and is neutralized by bearings and (2) a turning component that rotates the socket ring and, with it, the cylinder barrel and the output shaft.

After a given piston has taken all the fluid it can from the intake side of the valve plate, it passes the land and begins to discharge fluid through the outlet ports of the B-end to the intake (suction) side of the A-end.

The direction of turning of the B-end and its output shaft depend on the direction of turning of the A-end.

RECOIL AND COUNTERRECOIL DEVICES. The recoil and counterrecoil systems of naval guns operate without pump or motor action. Details of these piston-and-cylinder systems vary with the sizes and types of guns. Figure 3C12 is a representative sketch, based on a conventional 5-inch gun.

The recoil cylinder contains fluid and has a piston whose head is precision-fitted to the cylinder wall. The counterrecoil cylinder contains air (or some inert gas) under pressure and has a partially hollow plunger whose outer end extends through an airtight fitting in the end of the cylinder.

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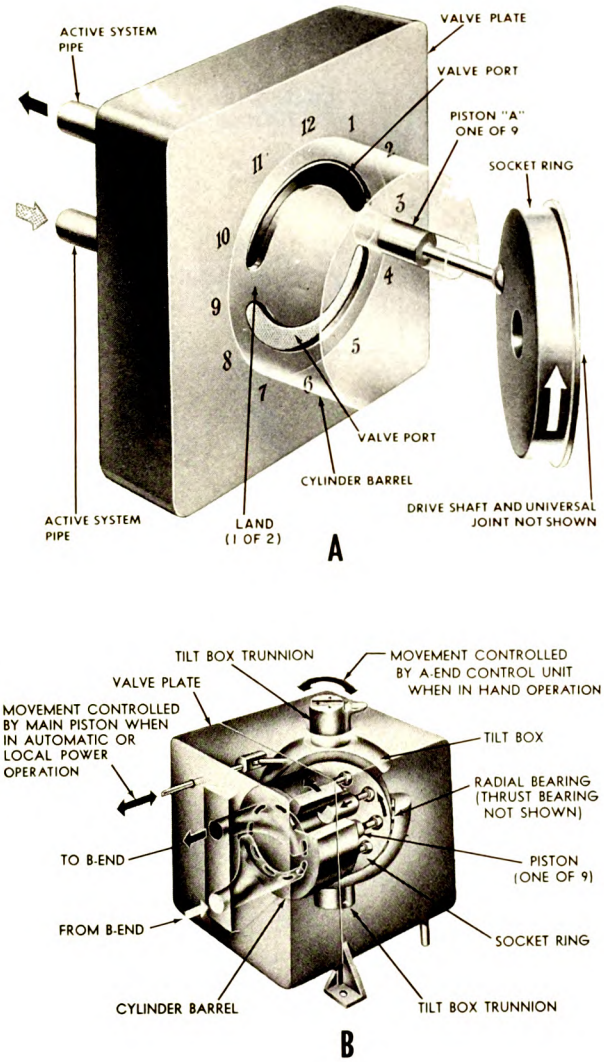

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Figure 3C9.—A-end operation. A. Cylinder barrel, valve plate, and socket ring; B. Phantom view of assembly.

The recoil and counterrecoil units work together to keep the "kick" of the gun within reasonable bounds, to restore the gun to battery, and to hold it there until the next round is fired.

If the student understands two simple and useful hydraulic devices—the hydraulic recoil brake and the differential cylinder—he should be able to study, with little difficulty, the specific recoil-counterrecoil mechanisms in any naval gun.

In a hydraulic recoil brake, the head of a piston fits closely within a fluid-filled cylinder. The passages from one side of the piston head to the other are few and small. These passages may be holes through the piston head, or they may be grooves in the cylinder wall. If an applied force (such as the shock of firing) acts to move the piston with respect to the cylinder (or vice versa) the movement can take place only as fast as the small passages allow fluid (which is practically incompressible) to flow from one side of the head to the other. Movement, therefore, is throttled, because much of the applied force has to be used up in overcoming resistance.

This principle is applied in the gun's recoil cylinder. The design features may vary from one gun to another, but the purpose remains the same.

A number of other ordnance braking devices, including, for example, the dashpots that delay the operation of certain linkages in moored mines, make use of the throttling effect of small orifices.

To absorb the final shock as the gun returns to battery, some guns have a dashpot-type counterrecoil buffer that is physically associated with the recoil cylinder.

As previously mentioned, the counterrecoil cylinder contains air or possibly some inert gas. Gases, of course, are fluids; but unlike liquids, they are capable of being compressed under pressure. When the pressure is removed, they expand. As can be seen in figure 3C12, recoil movement decreases the amount of space in the counterrecoil cylinder, thus putting the air under greater than normal pressure. In many guns, the increased internal pressure would tend to cause an air leak, except for the sealing effect of a comparatively small differential cylinder that acts to tighten the packing through which the plunger end extends. The next few paragraphs will take up the differential cylinder.

The device in the lower part of figure 3C13 is a typical differential cylinder. The free-floating piston in this cylinder always takes a position where the thrust of the air (directly connected to the air in the counterrecoil cylinder) exactly counterbalances the thrust of the oil (directly connected to the oil gland at the center of the chevron packing). But part of the area of the oil side of the differential cylinder head is occupied by the end of the piston rod, and therefore cannot receive thrust from the trapped oil, whereas the entire area of the air side of this head receives thrust from the trapped air. Therefore, at all times, the pressure in terms of pounds per square inch on the oil side must be

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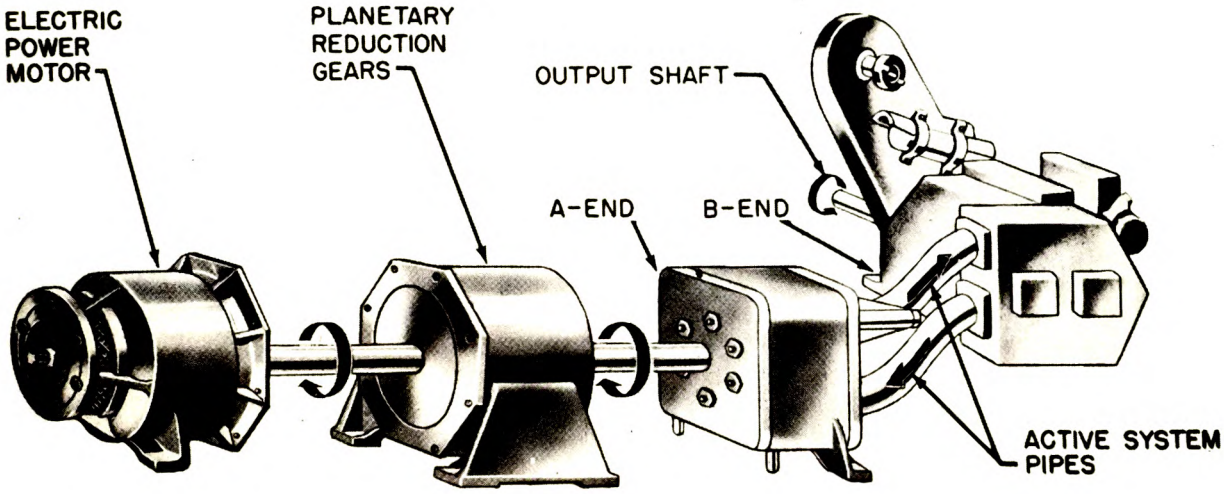

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Figure 3C10.—The hydraulic speed gear.

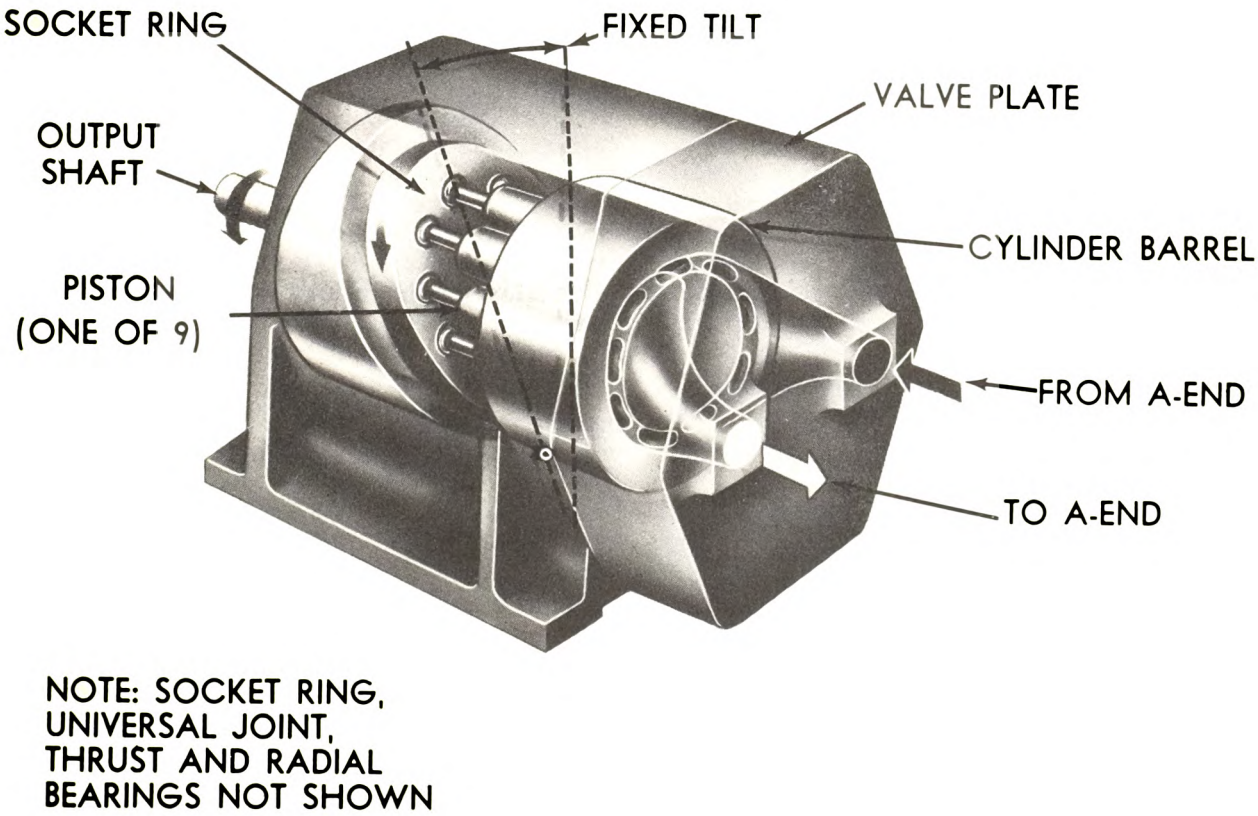

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Figure 3C11.—A phantom view of the B-end.

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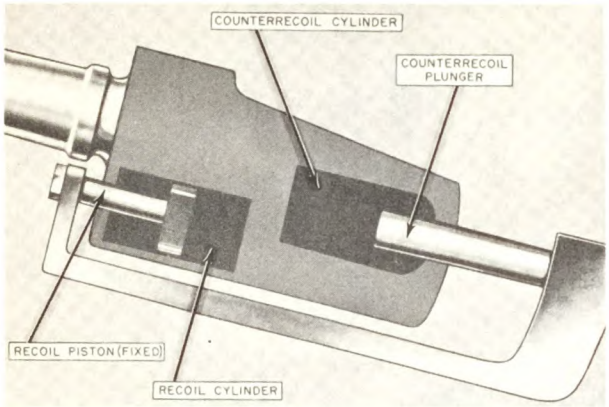
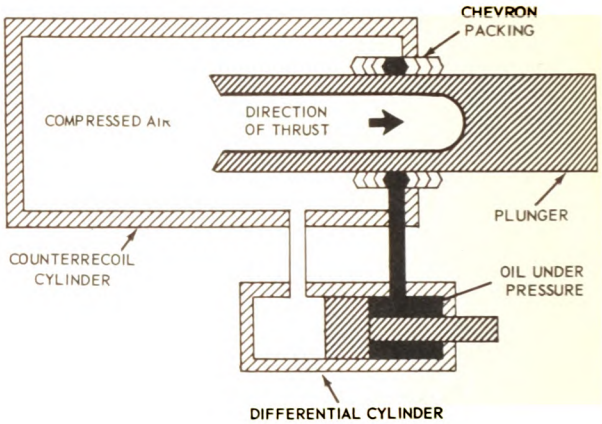


84.147
Figure 3C12.—Representative recoil and counterrecoil systems.



84.148
Figure 3C13.—Principle of the differential cylinder.

greater than the corresponding pressure (in psi) on the air side.

Whenever recoil action raises the air pressure, the unit pressure of the oil—including, of course the oil in the packing gland—rises proportionately. Thus the oil at the center of the specially shaped packing acts to "inflate" it and prevent leakage of air. Any leakage that occurs will be an oil leak, not an air leak.

As soon as the recoil action is completed, the air in the counterrecoil cylinder begins to expand and return the gun to battery. The oil side, of course, continues to exert greater unit pressure than the air side, and therefore acts to seal the counterrecoil plunger.

D. Basic Principles and Applications of Electricity

3D1. BASIC DEFINITIONS AND CONCEPTS

Electricity is a form of energy. As such, it can be harnessed to do work.

Electrons make electricity available for use. Normally an electron revolves within a parent atom, somewhat like a planet within a solar system. Every electron bears an electric charge. If set free from its atom—whether by chemical action or by other means—the electron takes its charge with it.

All substances have resistance, which is a tendency to block the movement of free electrons. Conductors have a relatively low resistance; insulators, a high resistance. The unit of resistance is the ohm. In electrical equations, R stands for resistance in ohms.

CURRENT is a stream of free electrons moving through a conductor. Current flows when (and only when) there is a closed circuit from the current source back to the source. Current is measured by the number of electrons that pass a given point in a second. The unit of current is the ampere. In equations, I stands for current in amperes.

Each point in an electric circuit has a potential or an electromotive ("electron-moving") force that corresponds roughly to head in a water system. Electromotive force is commonly abbreviated emf; its unit is the volt. In equations, E stands for an emf in volts. The emf at any point is mathematically equal to the product of the current and the resistance; this

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principle is called Ohm's law. It may be expressed in three equations:

$E = IR$, or by simple algebra,

$I = \frac{E}{R}$, and

$R = \frac{E}{I}$.

The unit of electric power is the watt. The power in watts is equal to the product of the current and the voltage. P is the symbol for power in watts. It may be expressed in the equation:

$P = EI$, or, by substitution from Ohm's law,

$P = E \times \frac{E}{R} = \frac{E^2}{R}$, and

$P = IR \times I = I^2R$

Electric current is of two types—direct and alternating. In direct current (d-c) the electrons move continuously in one direction, though not necessarily at a constant speed. In alternating current (a-c) the direction of electron movement reverses rapidly and repeatedly. The number of times the electrons reverse in one second is called the FREQUENCY. Navy ships commonly use frequencies of 60 cps (cycles per second) or 400 cps.

Electricity and magnetism are closely related. Any conductor carrying electric current is surrounded by a magnetic field.[1] Furthermore, a magnet will induce a voltage in any conductor that is moved in its magnetic field. Conversely, if a current-carrying conductor is placed in a magnetic field, the conductor will tend to move at right angles to the field.

When a conductor is twisted into a coil and energized by current, the coil, as a unit, has a magnetic field. When the field of an energized coil is changing in strength (because of a change in current), it can induce a voltage in a second coil that is not physically joined to the first one.

A TRANSFORMER is designed to make practical use of induction. In the transformer a current-carrying coil, called the primary, induces a voltage in another coil or group of coils, called the secondary.

An induction device called the synchro is taken up later in this chapter.

3D2. CURRENT SOURCES

Batteries and generators are the two usual sources of electric current. A battery uses chemical energy to produce electrical energy that becomes usable when an external conductor is joined to the two pole pieces of the battery. Batteries are used to energize the small, self-contained electrical systems in flashlights, independent mines, some depth charges, and numerous testing devices. Larger batteries are used to operate electrically driven torpedoes. (See chapter 11.) Very large installations are designed to furnish propulsive power for submarines. Batteries produce direct current only.

A GENERATOR uses mechanical energy (as from a steam or gasoline engine) to produce electrical energy by causing relative motion between an armature and a powerful magnetic field.

In most d-c generators the armature is the rotor, or turning member, and the magnetic field is furnished by the stator, or stationary member. Alternating current is always produced in the armature windings. In d-c generators the armature windings are connected to a commutator on the armature shaft. Stationary brushes on the stator contact the rotating commutator so as to receive electrons moving in one direction only. Thus the commutator-brush arrangement converts the a-c armature output to direct current.

Some a-c generators are constructed much like the d-c generator, except that they use solid annular insulated slip rings (instead of segmented commutators) and brushes. These directly transfer the a-c output to the external circuit. Larger a-c generators, however, use rotors with d-c excited electromagnets fed through brushes and slip rings, while the armature windings are in the stator. In still another variation, some special-purpose a-c generators have neither slip rings nor brushes; in these all windings, both armature and field, are in the stator, while the rotor consists of a metal core. The a-c damping generator mentioned below is of this kind of construction.

[1] A piece of iron or other magnetic material may have its own permanent magnetic field independent of any electrical current. This phenomenon, as distinct from the magnetic field surrounding a current-carrying conductor, is discussed further in chapter 12 in connection with degaussing.

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Figure 3D1, part A, shows the amplidyne train drive motor assembly on a 5-inch gun mount. The amplidyne system will be described in a later article, but this part of the figure is intended chiefly to illustrate examples of two types of motor and a d-c generator.

In general, ordnance systems do not generate electricity except for relatively small control voltages employed in "damping" (stabilizing) the operation of servosystems. In the amplidyne system, which is a d-c servosystem, the stabilizing voltage is generated by a small d-c generator (labeled "tachometer generator") mechanically connected to the shaft of the main drive motor. As you can see in the figure, the generator possesses the armature, field, commutator, and brushes mentioned above. In this illustration the tachometer generator is too small to show all these features clearly, but the student can inspect the corresponding features (which are similar in appearance and construction, though larger) in the main d-c drive motor.

Small a-c damping generators (not illustrated) are used in some a-c servosystems. In external appearance as well as internal construction they resemble the servomotor illustrated in figure 3D1, part B; or they may be built on cylindrical rather than square-ended frames.

3D3. MOTORS

Structurally, motors in general resemble generators. A motor has a fixed stator and a rotor that can revolve. Instead of producing current, the motor receives current and uses it to energize its windings and produce torque. In nearly all types of motors, the torque normally causes the armature to revolve. In all large motors (i.e., larger than a fraction of a horsepower) locking or stalling the rotor so that it cannot turn when the motor is energized by its rated voltage will burn out either the motor or its current source, if not protected by fuses (and burnouts can often occur even with fuse protection, too). Some small specialized types of motors are designed to withstand locked-rotor currents. In one such type of motor, called a torque motor, the rotor can turn only a few degrees in normal operation; in other types it is expected that the rotor will stall for a time in normal service.

Motors used in ordnance gear always have the field winding in the stator; if there is an armature winding, it is in the rotor With the rare exception of some machines that use permanent-magnet fields, d-c motors always have armature windings, commutators, brushes, and field windings. The main train drive motor shown in figure 3D1, part A, is a d-c motor with these components.

In all motors, the rotor is driven by the interaction between the magnetic fields produced by the stator and those produced by the rotor. In nearly all d-c motors and many a-c motors the interacting magnetic fields are produced by currents fed to the rotating armature windings and to the stationary field windings. In some a-c motors, however, currents are fed only to the field. The fluctuating magnetic fields produced by the a-c field currents induce other currents in the rotor; in turn, the induced rotor currents develop magnetic fields that interact with those of the field to develop motor torque. Motors that function on this principle are called INDUCTION MOTORS. The armature for such a motor may consist of a cage-like copper structure imbedded in a laminated soft iron core (these are called "squirrel-cage" motors), or of an aluminum or copper cup surrounding an iron core. Large a-c induction motors may have rotors with coil windings (these are called "wound-rotor" induction motors).

There are, in contrast to the restricted number of fundamental types of electric generator, a great variety of types of electric motor (including a-c, d-c, and "universal" motors operating on either type of current) some of them quite different in principle from others. The types most frequently encountered in ordnance equipment are:

1. Polyphase a-c induction motors. These are the large motors, developing from 5 to over 100 horsepower, used to operate gun power drive electric-hydraulic and amplidyne systems, hoists, rammers, and the like. Figure 3C10 shows such a motor. As a class they are characterized by high starting torque and fairly constant speed under varying load.

2. Single-phase a-c induction motors. These have different characteristics from polyphase motors, but work on similar principles. They comprise the fractional horsepower motors used to operate small blowers, windshield wipers, etc. The blower motor in part A of figure 3D1 is an a-c single-phase squirrel-cage induction motor.

3. Synchronous a-c motors. (Not illustrated.) Synchronous motors can be very large (they have been used to drive ship's screws) but in

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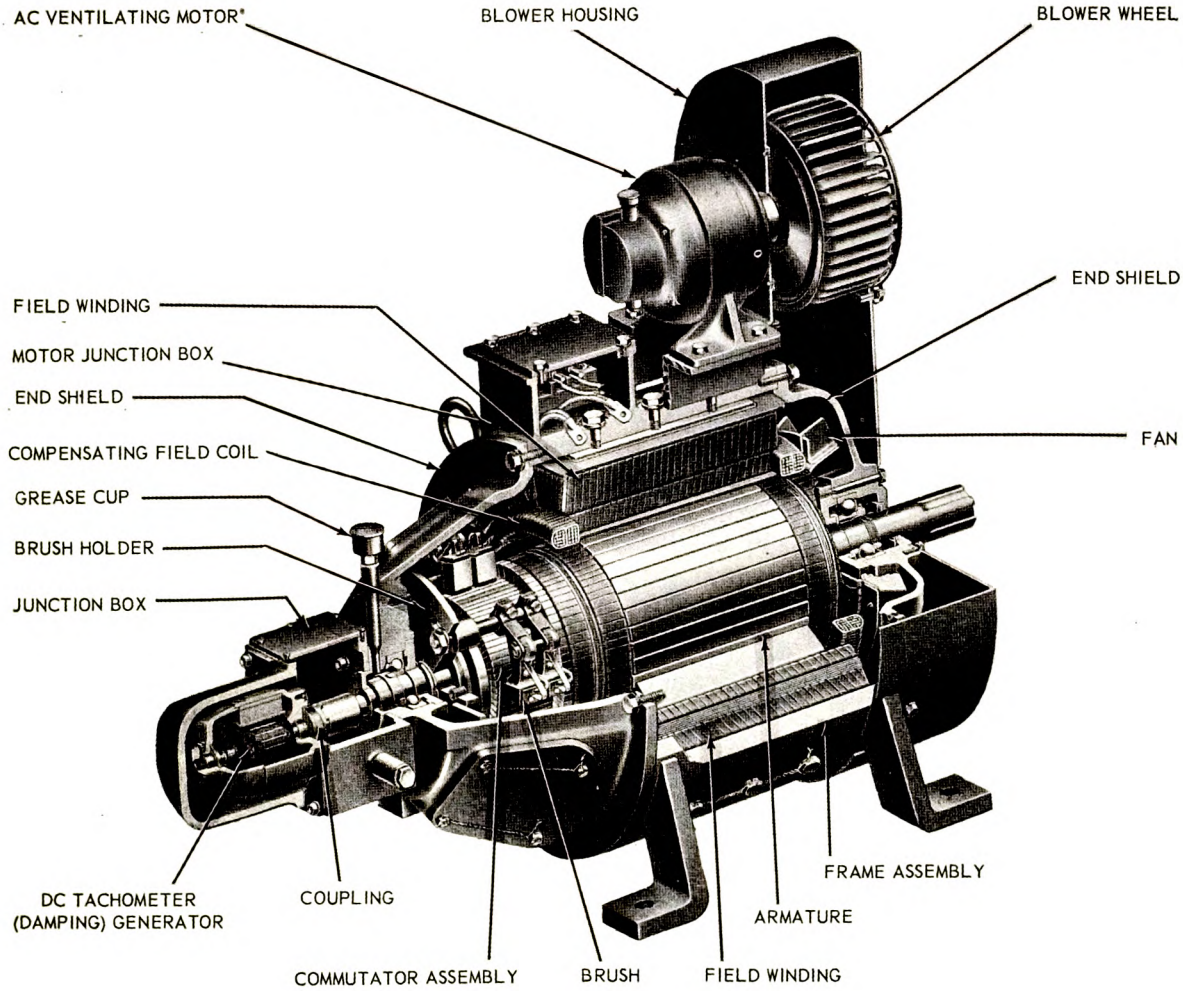
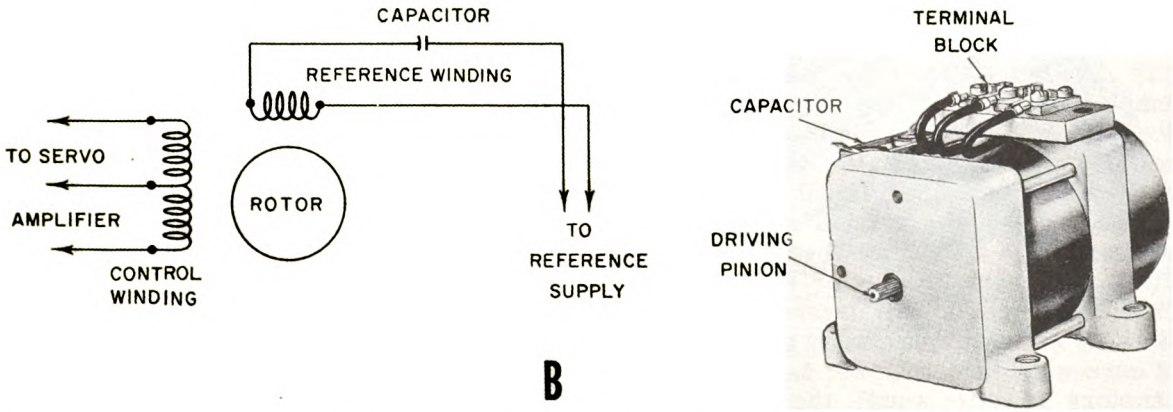


A



B

Figure 3D1.—Generators and motors. A. Amplidyne train motor assembly. (Note the d-c tachometer (damping) generator on the right and the a-c ventilating motor on the top of the assembly.) B. Typical small a-c instrument servo motor and its circuit diagram.

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ordnance equipment you will find only very small induction-type units designed to drive light loads, such as computing mechanisms, at absolutely unvarying speed. On most ships a special a-c constant-frequency supply is provided to drive such motors, since they can hold a constant speed only in so far as the frequency of their a-c supply remains constant.

4. Servomotors. The function of the servomotor will be explained later in this section. Its important characteristics are that (1) it must be reversible when its input is reversed, (2) it must develop (for its rating) substantial starting torque, and (3) its output torque must be at least roughly commensurate with its electrical input. (These characteristics are by no means applicable to all types of electric motors.) Servomotors used in ordnance equipment are nearly always of either of two main types:

a. A-c instrument servomotors. These are small fractional-horsepower induction motors powered by two inputs—(1) the ship's a-c power supply and (2) the output of the servo-amplifier. Figure 3D1, part B, illustrates one type of a-c servo motor and its circuit. The motor is always directly geared to the load, which may be a small indicator or computing mechanism component, a synchro, etc. (Synchros will be taken up later in this section.) It may also be geared to an a-c damping generator. Conventionally, the motor has two windings. One, the reference winding, is continuously energized by the ship's a-c supply (which is often called the REFERENCE VOLTAGE.) A capacitor is usually in this circuit. The other winding receives the amplifier output, which is an alternating current of the same frequency as the reference supply, but differs in phase from the current in the reference winding. This means that at any instant, it will differ in magnitude and often in polarity from the reference supply. In most servomotor circuits the capacitor functions to develop this phase difference. When only the reference supply is fed to the motor, its rotor (which has no winding but is only an aluminum or copper cup, shell, or cage secured to the output shaft) will not turn. When the amplifier puts out a current, the motor will develop a torque whose direction will depend on the phase relationship between the reference and amplified output currents. Since the power developed by a-c servomotors is quite small, the motor output may itself be used to control a hydraulic servo which develops greater power.

b. D-c mount power drive motors. These motors are high-powered units used as described below in conjunction with amplidyne generators to drive gun mounts in train and elevation. The main drive motor shown in figure 3D1, part A, is of this type.

3D4. POWER TRANSMISSION

In a small electrical system, like that in a torpedo or mine, the power source, the transmission lines, and the simple or elaborate operating equipment must all be scaled down to fit a limited space. In an electrical system serving a city or a countryside, the power demands are heavy, and large-size components are necessary. Alternating current from huge generators may be transported for long distances over high-voltage lines. Transformer stations, making practical use of the principal of induction, convert the current and voltage to values safe for industrial and residential use.

Shipboard electrical systems occupy a position somewhere between these two extremes. The ship's main generators, connected to a cable system through two or more switchboards, supply current for many routine uses. The total power available must be great enough to meet the demands of varying conditions, including battle.

All possible safety precautions are observed. The cables pass through special packing glands between one ship unit and the next. Junctions and splices are made through special boxes and terminal boards. Tests are frequent and thorough.

Turrets and mounts have their own very elaborate wiring systems. Specific wiring systems are described in the BuWeps publications (OP and OD) for the ordnance installations.

3D5. ALTERNATING CURRENT

In alternating current, as previously mentioned, the direction of electron movement reverses rapidly and repeatedly. Though still applicable, Ohm's law no longer deals with simple resistance as the single obstructive effect that limits current flow at a given voltage. In a-c circuits, specific types of circuit elements also have other obstructive effects on current flow, and these effects vary with the a-c frequency. These effects are called CAPACITANCE and INDUCTANCE, and in any a-c circuit they must be taken into account along with resistance. These

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effects are not restricted to obstruction of current flow; as we previously noted in connection with the explanation of the capacitor in a-c servo motor operation, they can change the phase of one a-c voltage with respect to another.

In addition, there are still other ramifications to this subject. Though they are important to detailed consideration of the functioning of all electrically operated ordnance equipment, these aspects of a-c theory are beyond the scope of this course. Junior officers assigned to communications or fire control will find that the enlisted men specializing in these fields are well grounded in theory, as well as in its practical applications. The ordnance publications on specific items of equipment frequently cover those aspects of the theory that are assumed to be new in the reader's experience.

3D6. SYNCHROS

INTRODUCTION. A synchro is an a-c energized device that looks like a small motor or generator, but is closer in operating principle to the transformer. All synchros have a wound rotor and a wound stator, with slip rings and brushes to connect the rotor windings to the remainder of the system.

In terms of functioning principles, there are 5 types of synchro:

Synchro transmitter
Synchro receiver
Synchro control transformer
Synchro differential transmitter
Synchro differential receiver

Any synchro system includes two or more of these units, one of which must be a synchro transmitter. Synchros are made in standard sizes and electrical characteristics, in two main varieties—one designed for operation at 60 cps, the other variety designed for operation at 400 cps. Principles of functioning apply regardless of difference in size and frequency rating. To understand these principles, we'll discuss first a system comprising a transmitter and a receiver, then go on to the other types.

SYNCHRO TRANSMITTERS AND SYNCHRO RECEIVERS. A synchro transmitter (also called a synchro generator) transmits an electrical signal that varies with the angle of rotation of its shaft. This signal goes through three conductors to a synchro receiver (also called a synchro motor). An additional pair of conductors finishes exciting voltage from the a-c reference supply to both the receiver and the transmitter. See Figure 3D2. The synchro receiver responds by causing its own shaft (if not too heavily loaded) to rotate through an angle corresponding to the signal. The two shafts turn through the same angle and in the same direction (for example, both 30° clockwise or both 15° counterclockwise, and so on). See figure 3D3.

The two drawings in figure 3D3 show how a transmitter or receiver (these are electrically similar) is constructed. The stator contains three evenly spaced, electrically connected coil windings. The centrally located rotor is also wound as a coil. The rotor winding is excited by the a-c reference supply.

When alternating current flows in the rotor, it creates a rapidly reversing magnetic field. This field induces currents in the stator coils; the stator currents produce fields whose total effect, or resultant, at any given instant, directly opposes the field of the rotor.

To form a conventional transmitter-receiver arrangement, two synchros are wired as shown in figure 3D4. Normally, however, the distance separating the synchros is much greater than the drawing indicates.

In their at-rest position, the two synchros are as shown in part A of the illustration. An input (through gearing or a handcrank) turns the rotor of the synchro transmitter as shown in part B. This upsets the balance of the magnetic fields throughout the system.

In restoring the system to magnetic balance, the electromagnetic forces acting on the synchro receiver turn its rotor to a position corresponding exactly to the position taken by the rotor of the transmitter. See part C of figure 3D4.

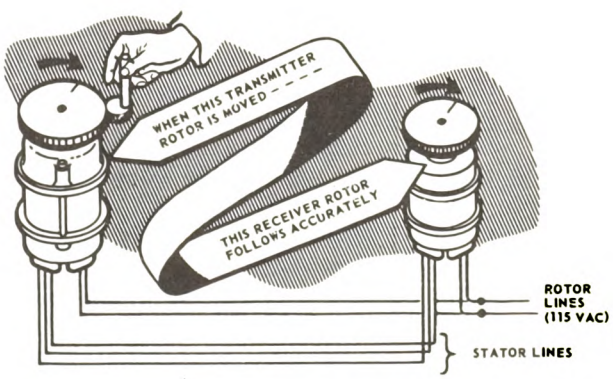

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Figure 3D2.—An elementary synchro system.

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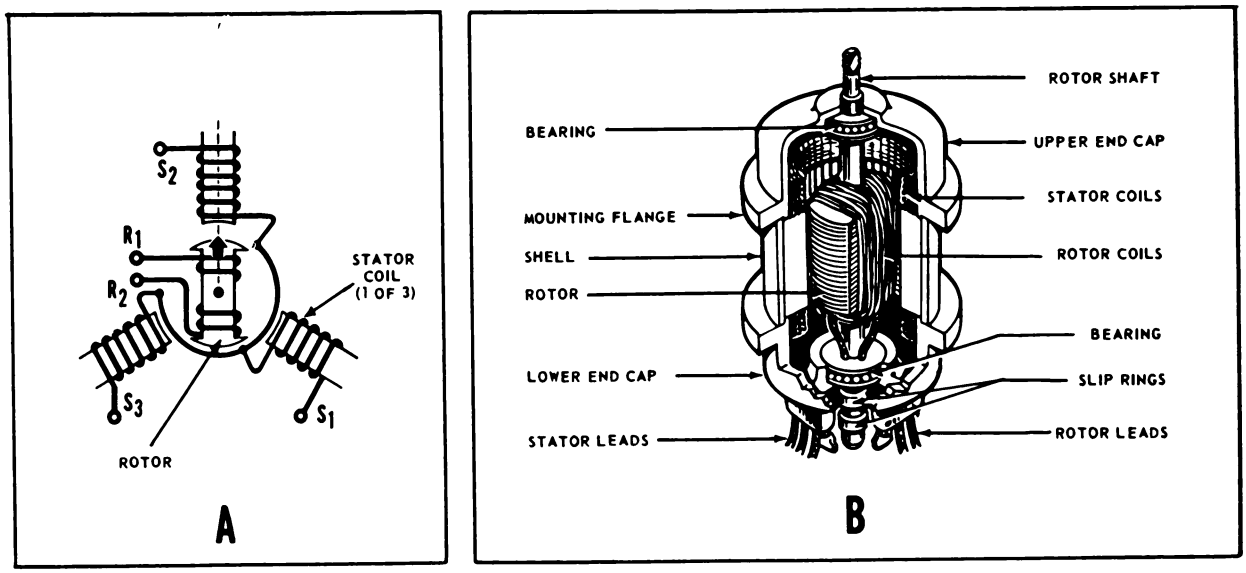

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Figure 3D3.—Inside a synchro. A. Schematic drawing; B. Realistic drawing.

When the signal changes again, this sequence of events is repeated.

A synchro receiver of the type just described can be connected through shafting and gearing to turn a very light load, such as a dial. It is not powerful enough to turn a heavy load like a gun mount or a missile launcher. A special kind of synchro receiver called a control transformer can, however, act through a motor to turn a fairly heavy load.

SYNCHRO CONTROL TRANSFORMER. Like the basic synchro receiver, the control transformer receives an electrical input signal from a synchro transmitter. In the control transformer, however, the rotor is designed to produce an output voltage proportional to the incoming signal. After being amplified, as shown in figure 3D6, this output voltage drives a motor (called a servomotor) that operates a gearing system to turn the load.

SYNCHRO DIFFERENTIALS. Two types of synchros used in fire control are similar in purpose to the mechanical differential that continuously adds or subtracts two changing inputs.

The synchro differential transmitter (also called a differential generator) receives two inputs: (1) a mechanical signal that turns its rotor and (2) an electrical signal that is fed into the stator windings. The output of this synchro is an electrical signal that exactly measures the sum (or, if wired for this purpose, the difference) of the two inputs.

The synchro differential receiver (also called a differential motor) combines two electrical signal inputs to produce a mechanical output. This output consists of a rotor torque or movement that accurately represents either the sum or the difference of the two inputs.

USING PAIRS OF SYNCHROS. The accuracy with which a synchro receiver or control transformer will duplicate the signal from the transmitter is on the order of a few minutes of arc difference between the signal as transmitted and the signal as received. In some applications, a few minutes' inaccuracy is not important, but in others it is. For high-precision applications, a pair of synchro transmitters is geared together in the ratio of 36:1, and is connected electrically to a pair of receivers or control transformers similarly geared together. In each pair, the unit that rotates more slowly is the low-speed or coarse unit; the other is the high-speed or fine unit. You can liken this arrangement to the hands of a clock, with the clock hands geared 36:1 rather than 12:1. The hour hand corresponds to the coarse or low-speed indicator, and the minute hand to the fine or high-speed indicator. When pairs of synchros

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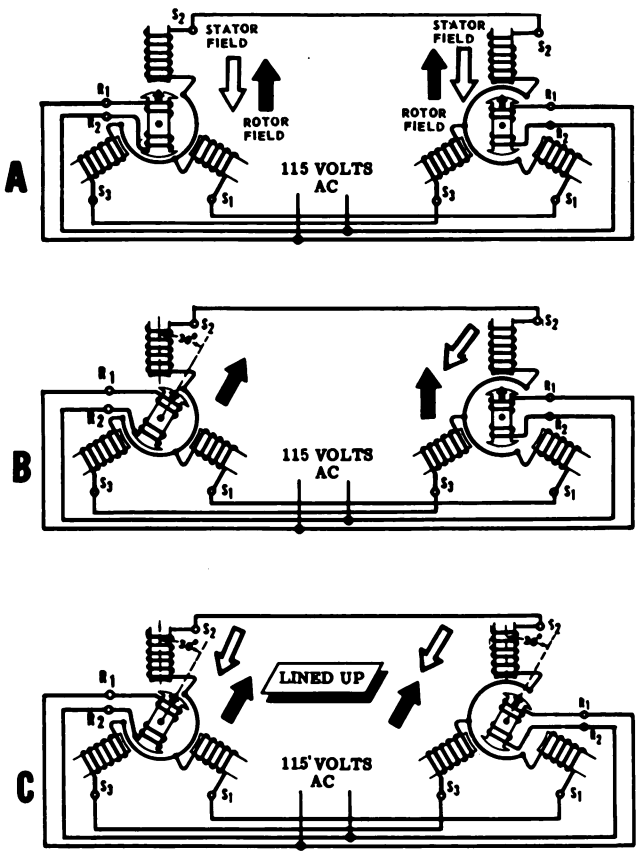

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Figure 3D4.—A representative synchro system.

are used, the coarse unit covers the full range with which the system deals, while the fine unit, which rotates a number of times for one rotation of the coarse unit, makes it possible to transmit with much better accuracy than would be possible with the coarse unit alone.

3D7. SERVOMECHANISMS

WHAT THEY ARE. Electrical arrangements that cause mechanical action to take place automatically in response to synchro signals are called followups or servomechanisms. A servomotor is one of the components of a followup.

A servomotor is a reversible motor that operates in a slave-to-master relationship with the synchro equipment from which it receives its input signals. There are both a-c and d-c types of servomotors. The one mentioned later in this chapter, in connection with amplidyne power drives, is a d-c type. Certain dials and mechanisms in computing equipment are turned by a-c types.

Figure 3D5 illustrates in a simplified schematic the elements of a servosystem. The functioning of such a system is described below with reference to how its principle is utilized in positioning a gun.

1. At a remote station, all available information about the target is collected and combined. To the gun mount is transmitted a pair of order signals telling, respectively, what values of train and elevation will put the gun in firing position. The gun has two power drive systems—one for train and one for elevation. One of these is shown in figure 3D5. Each system receives its own order signal and performs, independently, the actions outlined below.

2. The order signal is compared with the actual position of the gun. The result of this comparision is a command (called the error signal) telling how far and in which direction the gun must move.

3. When properly amplified, the error signal operates the controls of a power drive.

4. The power drive moves the load in such a way as to reduce the error.

5. While the load is being driven, a response signal is sent back continuously and automatically for comparison with the order signal.

6. When the two error signals (train and elevation) have been reduced to zero, the gun is in the ordered position for firing.

A-C INSTRUMENT SERVOMECHANISM. Now consider how the servo principle is applied in a typical instrument servomechanism or "followup" using an a-c reference voltage. Compare figures 3D5 and 3D6. In figure 3D6 the parts in the mechanism corresponding to

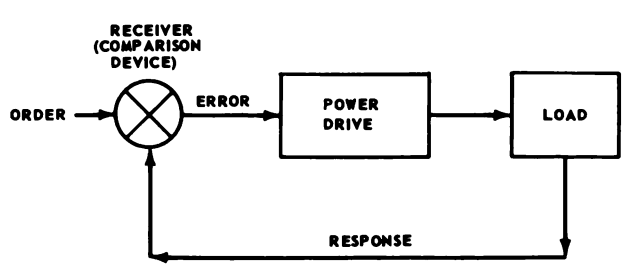

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Figure 3D5.—Basic servosystem.

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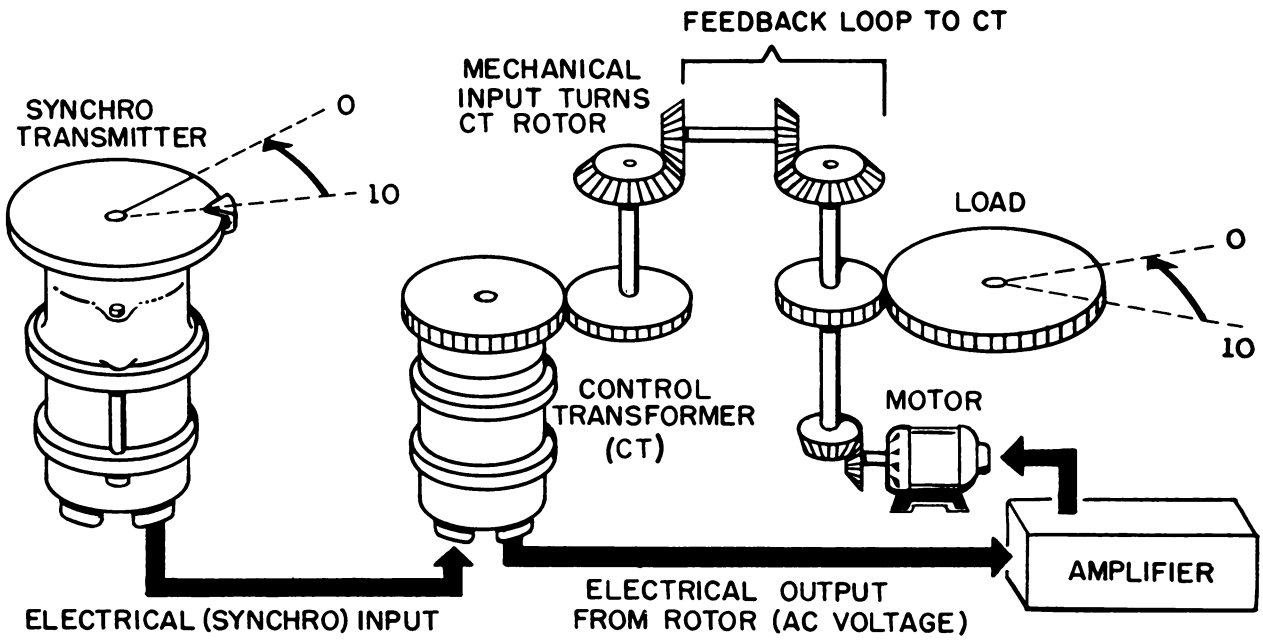

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Figure 3D6.—A-c instrument servomechanism. Pictorial functional schematic.

the diagram of figure 3D5 are a synchro control transformer which serves as the signal receiver and comparison device, an electronic amplifier and a-c servomotor which together correspond to the power drive, and gearing from the motor which drives the load and the synchro control transformer rotor. The amplifier may be of the tube, magnetic, or transistor type, or a combination. The load may be a dial, a computing device, a hydraulic valve, a synchro transmitter, etc. We omit a number of components used in many systems to improve the stability and response of the servo, such as damping generators, amplifier feedback and stabilizing circuits, discrimination circuits which automatically select the appropriate input signal, capacitors for improving electrical characteristics and for changing phase relationships, etc.

The input that starts the servomotor is the output voltage of the synchro control transformer. This voltage has to be amplified before it can be used. As the servomotor turns, in response to the input voltage, the rotor shaft furnishes a mechanical output to the gearing that turns the load.

The load in figure 3D6 is connected back, through gearing, to the rotor of the synchro control transformer. The result of this mechanical feedback is to drive the rotor in such a direction as to reduce the electrical output of the control transformer. When the load reaches the position originally ordered, the output of the control transformer becomes zero, and the motor stops.

The example chosen is a common type of servomechanism, but many other varieties and combinations of components are possible. It is possible to use a mechanical differential, an electrical resolver, a synchro differential transformer, a special type of movable-core transformer, or any of several other devices for the error-sensing unit. The variety possible in amplifiers has already been hinted at, as well as in auxiliary circuits and devices. Several kinds of motors are available, and so on. But the servo principle underlies all these combinations.

Now let us consider larger and more elaborate servosystems used for a gun mount, launcher, or fire control director.

3D8. AMPLIDYNE SERVOSYSTEMS

Heavy guns can be (and sometimes are) trained and elevated by direct handwheel action

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through the gearing system. Naturally this relatively slow and difficult method is not normally used in battle. But it is necessary for certain adjustment or maintenance operations.

For moderately light loads—such as 3-inch and smaller gun mounts and gun directors—amplidyne power drives are reliable and accurate. They are easier to maintain than the electric-hydraulic systems designed for heavier guns.

In figure 3D7 an amplidyne followup system has been reduced to its bare essentials. These are a pair of synchro control transformers (illustrated as a single unit for the sake of simplicity), an amplifier, an amplidyne motor-generator, and a followup d-c servomotor.

In the synchro control transformer the input to the stator is an order signal from a remote synchro transmitter. The position of the rotor represents the reponse of the load. The output of the synchro control transformer is the a-c error signal. Actually, two synchro control transformers—a coarse and a fine one—are used. When the gun is within 3° of its ordered position, the fine synchro is automatically connected to control the system instead of the coarse one.

The control amplifier uses gas-filled electron tubes (called thyratrons) for two purposes. First it rectifies the a-c input; that is, it converts this input to a d-c output whose magnitude and direction measure the amount and direction of error. Second, it amplifies the signal and produces two d-c outputs that are fed to the control field windings in the amplidyne generator, as explained in the paragraphs following.

The amplidyne generator is a special adaptation of one type of ordinary commercial d-c generator. Such a generator has a wire-wound rotor that turns within the field of an electromagnet on the stator. The upper part of figure 3D8 shows a conventionally connected d-c field schematic. Excitation power to the field is 100

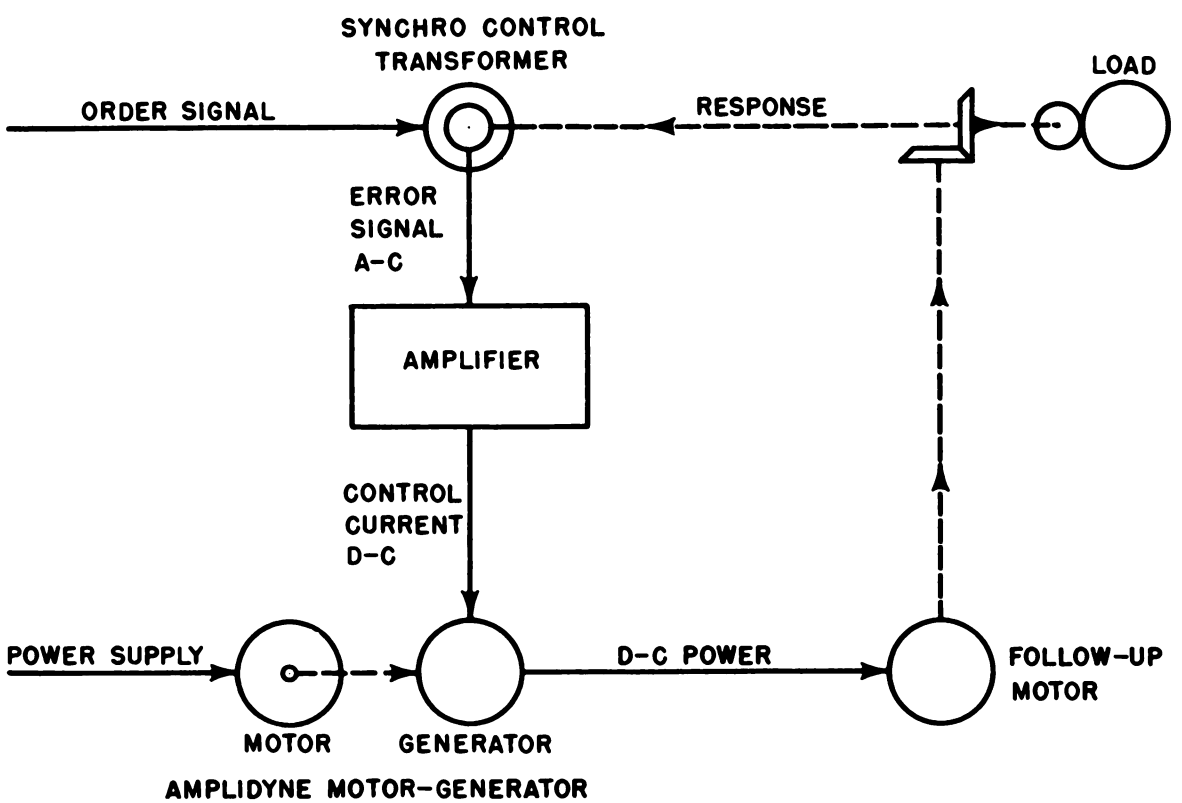

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Figure 3D7.—Essentials of an amplidyne followup system.

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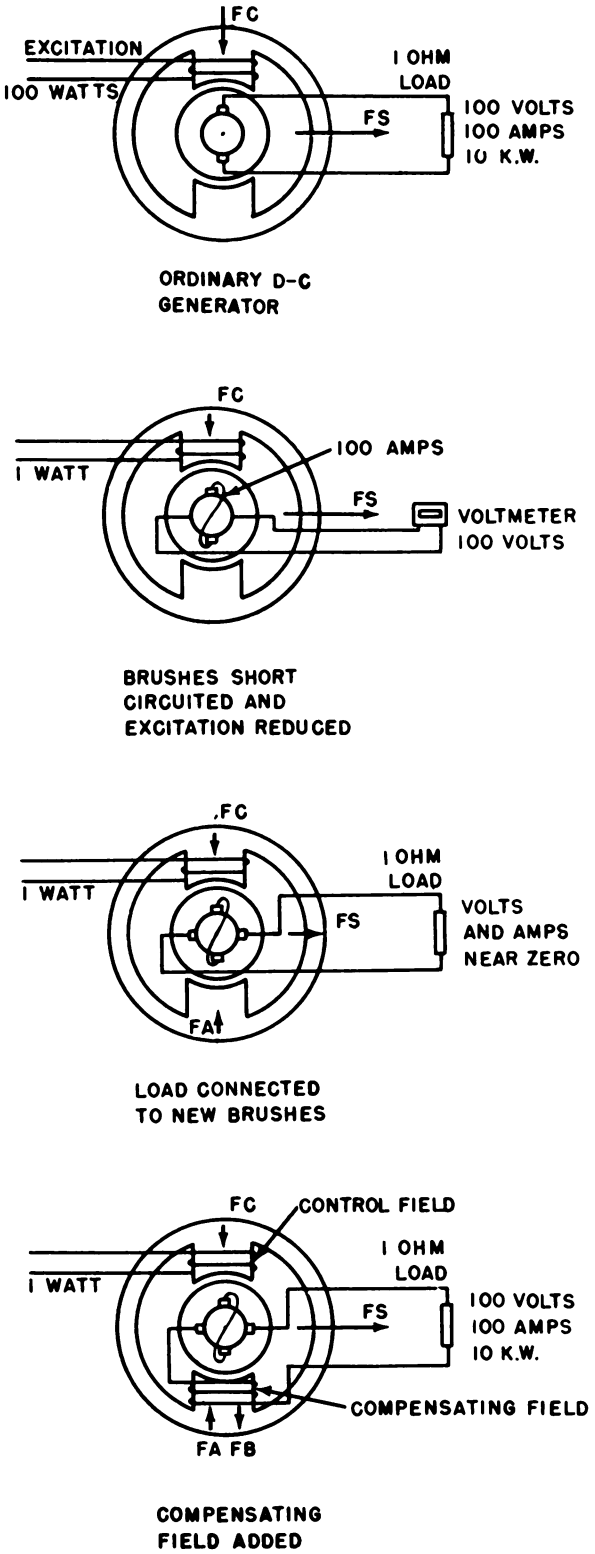

Figure 3D8.—The development of an amplidyne generator. 110.26

watts d-c to produce field FC. The arrow shows the direction of this field.

The larger circle between the two poles represents the rotating armature, which is driven at constant speed by a motor (not illustrated). Rotation in field FC induces an a-c voltage in the armature winding.

The inner circle in figure 3D8 represents the commutator. In the conventional d-c generator, the commutator connects the armature output to an external d-c load circuit by contact with a pair of stationary carbon brushes, 180° apart. The generated (or load) current as it passes through the armature winding creates its own magnetic field, FS. This field, called armature reaction, serves no useful purpose; indeed, it is a nuisance.

Normally, other things being equal, the power output of the generator will be proportional to the excitation power. This generator is assumed to be a 10-kw machine (10,000 watts output), and the excitation required is about 100 watts. The "amplification," therefore, is 100 to 1.

The first step in transforming this ordinary d-c generator into an amplidyne generator is to short-circuit the two brushes as shown in the second part of figure 3D8. Now an immense armature current will flow, but if excitation is cut down to about 1 watt, FC is reduced, and 100 amperes again flow through the armature, producing the same armature reaction FS as before.

The next step is to add a second pair of brushes at right angles to the short-circuited pair, and to connect the load circuit over these brushes, as shown in the third part of the figure. Now, however, the output voltage becomes very low, because the new output circuit has created its own armature reaction, FA, which opposes FC and greatly reduces its effect.

Now put a compensating winding, so connected that armature current passes through it, on the second pole of the electromagnet, as in the final part of the figure. This winding produces field FB to nullify FA and thereby allow FC to become fully effective again. The ordinary d-c generator has now become a basic amplidyne generator in which full-load output is developed with 1 watt excitation ("amplification" of 10,000 to 1). Thus it can operate on very low excitation (e.g., the output of the amplifier in figure 3D7) and still furnish enough power to drive a large servomotor (the followup motor in figure 3D7).

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The amplidyne generator must control the direction of its followup motor's rotation, as well as its torque. To accomplish this, the amplidyne generator has two control fields instead of the one shown in the last part of figure 3D8. One of these is wound in the opposite direction to the other. The direction of FC and of generator output depend on which receives more current from the amplifier. If the amplifier supplies equal currents to both control windings, generator output is zero and the followup motor stands still. When control winding currents differ, the followup motor will develop a torque whose direction depends on which current is greater, and whose magnitude depends on the amount of the difference.

The followup motor operates in a slave-to-master relationship with the amplidyne generator. Under a given load, its speed and direction of turning depend on the amount and direction of its d-c input from the generator. Its output is mechanical power to drive the load in the right direction until the error signal has been reduced to zero.

3D9. ELECTRIC-HYDRAULIC SERVOSYSTEMS

The electric-hydraulic power drive has been developed to perform heavy gun laying reliably and rapidly. Previous portions of the chapter have taken up the components of electric-hydraulic power drives. What remains to be done is to show how the several types of components work together in a unified system. These paragraphs will not go into fine details, but will limit themselves to summarizing major functions.

The order signals to an electric-hydraulic system normally originate at a remote station. They enter through a complex unit sometimes called an indicator-receiver-regulator, but more often shortened to indicator-regulator. This unit contains synchros and related devices for (1) receiving the order signal and the response, (2) computing the error signal, (3) amplifying the error signal, and (4) transmitting this signal to the hydraulic system through an arrangement of valves and pistons.

Figure 3C10 has already shown a typical gun mount electric-hydraulic power drive. The student should now be able to see how the various units—whether mechanical, hydraulic, or electric in nature—work together.

A conventional a-c electric polyphase induction power motor, connected to the ship's regular power supply, through a system of reduction gears drives the hydraulic pump (A-end) at virtually constant speed, regardless of A-end output.

The output of the A-end is hydraulic pressure to drive the B-end. The output of the B-end is mechanical action through a shaft and pinion. The input the B-end receives from the A-end determines the direction and duration of its output. In turn, the direction and amount of motion in train or elevation depend on the output of the B-end to the gun's gearing system.

To meet varying conditions, a gun mount's electric-hydraulic system allows a choice of several methods of control. Ordinarily the responsible officer or petty officer selects the most completely mechanized method that will work. The four methods of control that may be applied to a representative medium-caliber gun mount, the 5"/38, are designated as AUTO (automatic), LOCAL, HAND, and MANUAL.

Figure 3D9 shows the sequence of operations when the mount is trained in AUTO. (The train drive is illustrated, but the same principles apply to the elevation drive.) The gun order signal from a remote source enters the indicator-regulator. There the order signal is compared with the response, and the error signal is generated and amplified. The amplified error signal positions the A-end socket ring, thus regulating A-end output. A-end output drives the B-end, which drives the training pinion and rack. Mechanical response from the gearing is

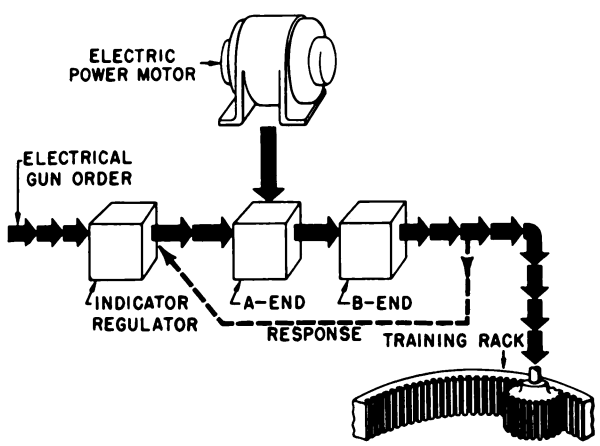

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Figure 3D9.—A train power drive in automatic control.

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an input to the indicator, where with the order signal it helps to generate the error signal. As gun position approaches synchronism with the gun order signal, the error signal decreases, becoming zero or null when gun position equals gun order.

In LOCAL control the trainer's handwheels, rather than a remote source, transmit the order signal to the indicator-regulator. As before, the indicator-regulator compares the order signal with the response and transmits the error signal to the A-end. From that point on, as shown in figure 3D10, the sequence of operations is the same as in AUTO control.

In HAND control (not available in all mounts) the trainer bypasses the indicator-regulator completely. The handwheels are geared to a mechanical followup on the A-end control unit, which still receives power from the electric motor. In response to the handwheels, the A-end operates the B-end until the trainer's dial system (or, alternatively, his optical equipment) assures him that the gun is at the ordered position. Figure 3D11 shows this sequence.

The fourth method, MANUAL control, is used chiefly to train the mount when repairs, alterations, or adjustments, are in progress. In this method the handwheels are geared directly to the training rack, bypassing the entire electric-hydraulic system.

OTHER CONTROL SYSTEMS. The foregoing examples of amplidyne and electric-hydraulic control systems have been taken from gunnery. Guns, however, are far from being the only military equipment that must be moved smoothly, rapidly, and accurately in response to incoming signals. Missile launchers and certain types of projectors have control arrangements similar, in many features, to those used with conventional guns. By their nature, systems designed to launch guided missiles must be capable of operating even more swiftly, accurately, and dependably than any except the newest gun systems. As in conventional guns, the designer's choice of amplidyne or electric-hydraulic drives is governed largely by the weight and other physical features of the given system.

Many types of lightweight equipment, both in the field of ordnance and outside it, contain electronic amplifier-rectifiers, synchros, servomotors, and simple or elaborate computing devices. Naturally this chapter cannot take up these types of equipment one by one. A reader who understands the basic mechanisms used in gun fire control, however, should have little trouble in following an instructional pamphlet that tells how similar mechanisms are designed to set a fuze, to train an antenna, or to steer a ship.

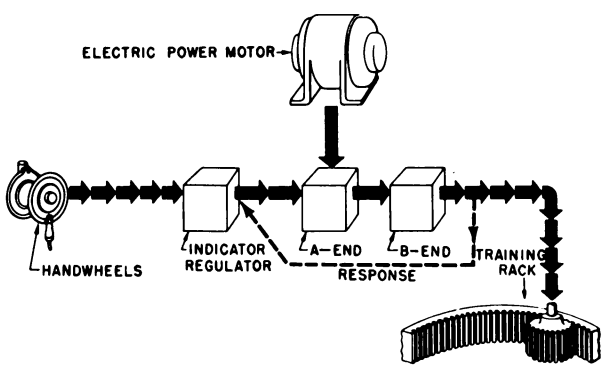

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Figure 3D10.—A train power drive in local control.

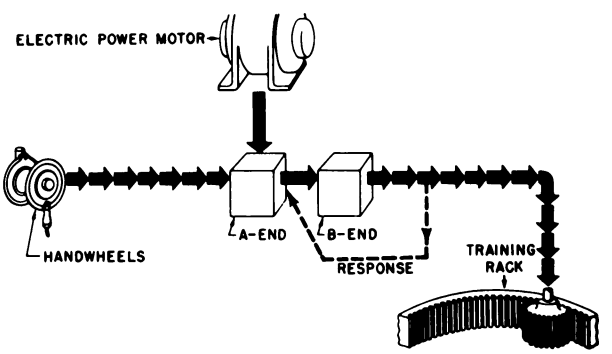

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Figure 3D11.—A train power drive in hand control.

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E. Principles of Optics and Ordnance Optical Instruments

3E1. FUNCTION OF OPTICAL INSTRUMENTS

The optical instruments used in naval fire control present a magnified image of the target to the observer's eye. At the same time, the observer sees an image of a reticle, or reference mark, located inside the instrument itself. By accurately superimposing the reticle image on the target image, the observer can establish an accurate line of sight to the target. The rangefinder, by establishing two separate lines of sight, makes it possible to find the target range by a form of triangulation.

To form the reticle and target images, an optical instrument must control the path of the light that passes through it. It does so by the use of lenses, prisms, or mirrors, or some combination of these elements. This section briefly reviews the behavior of light as it passes through optical elements. Familiarity with these basic principles will make possible a general understanding of most optical instruments.

3E2. NATURE OF LIGHT

Light is a form of energy. It travels from one point to another in the form of waves. Except for their wavelengths and frequency, light waves are identical with other types of electromagnetic radiation, such as radio waves and gamma rays. The wavelength of visible light ranges from approximately 0.35 micron to 0.70 micron. (A micron is one thousandth of a millimeter.) The color of light depends on its wavelength. In order of increasing wavelength, the colors are violet, indigo, blue, green, yellow, orange, and red. Radiation of longer wavelength then visible red is called infrared, or heat radiation. Beyond infrared are the radio waves, Radiations shorter than visible violet are, in the order of decreasing wavelength: ultraviolet, X-rays, gamma rays, and cosmic rays.

If a small object is dropped into water, a series of concentric circular waves will spread out from the point of impact. This provides a familiar analogy for the behavior of light waves. Waves in water, however, move on a two-dimensional surface; light waves move in three dimensions. The waves that move outward from a small source of light may be thought of as a series of concentric, rapidly expanding spheres.

In the study of optics it is convenient to trace the path of light rays, rather than waves. At any given point, a light ray is an imaginary line used to show the direction in which the light wave is moving. Since the wave is an expanding sphere, its direction of movement at any point is along a radius of that sphere. A ray, then, is a radius of the sphere formed by the wave front, and is at right angles to the wave front.

A telescope or similar instrument will receive only a small part of the light emitted by the source. Each wave that enters the instrument, therefore, is only a small part of a sphere. If a wave comes from a nearby source, the part of it that enters the instrument will be strongly curved. And the rays (radii of the spherical wave) that enter the instrument will be diverging. But if the source is at a great distance, the part of the wave that enters the instrument will be nearly flat; for all practical purposes it can be considered a plane. Since the rays are perpendicular to the wave front, the rays that enter an optical instrument from a distant point can be considered parallel. Figure 3E1 should make this clear.

In the drawings in this section only a few rays are used to represent the light that enters the instrument. But remember that light rays enter an optical instrument at every point on its first lens. In diagrams of optical instruments, only a few of these rays will be shown. Three rays are usually enough to show the path of light and formation of images within the instrument.

Light travels at about 186,000 miles per second in air. In a denser medium, it moves more slowly. For example, the velocity of light in water is about 140,000 miles per second; in glass it ranges from 95,000 to 127,000 miles per second, depending on the optical density of the glass. This difference in velocity makes it possible for an optical instrument to control the path of light, to form images, and to magnify them.

3E3. REFLECTION

When light traveling in air strikes the surface of a mirror, most of it is reflected back into the air (fig. 3E2). The incoming ray is the incident ray. The normal is an imaginary straight line, at right angles to the mirror surface, passing

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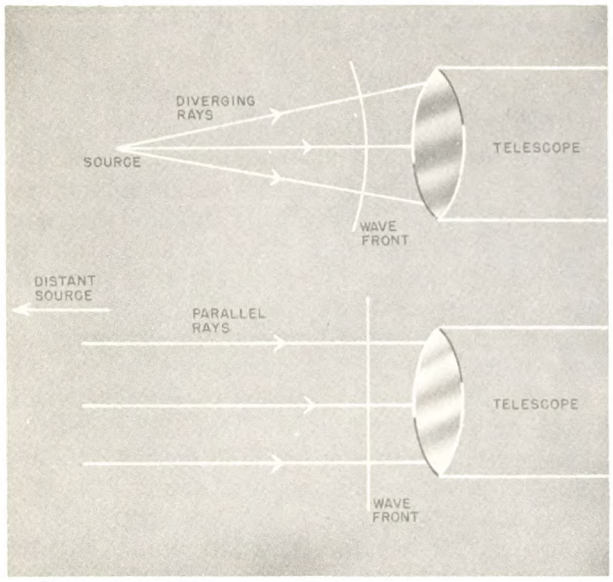

12.230
Figure 3E1.—Light rays from nearby and distant sources.

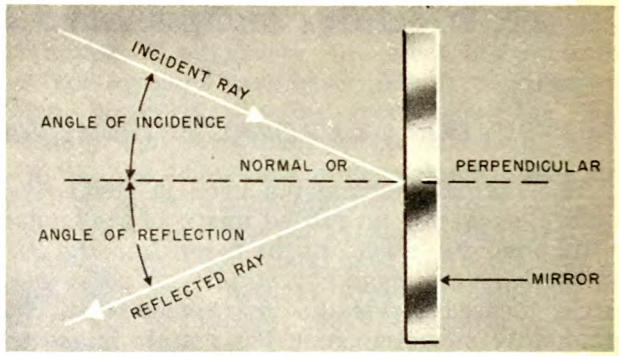

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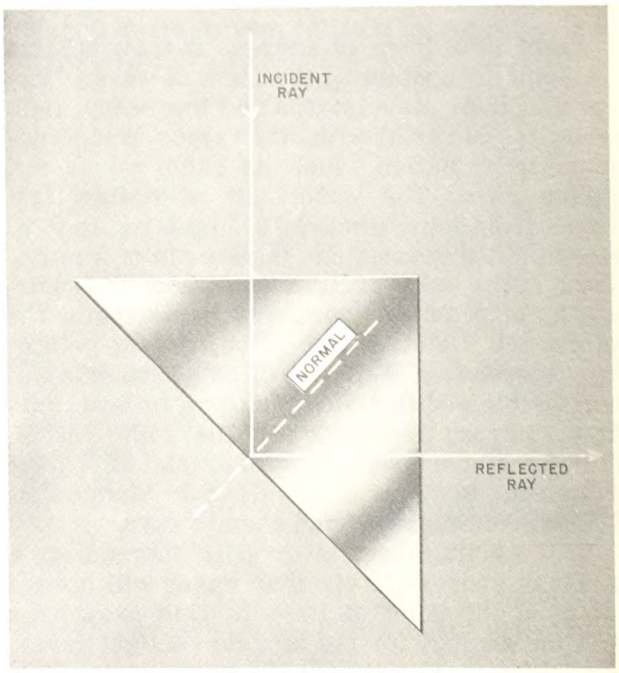
Figure 3E2.—Reflection at a mirror surface.

through the point of incidence. The angle of incidence is the angle between the incident ray and the normal, and the angle of reflection is the angle between the normal and the reflected ray. The law of reflection states, first, that the angle of incidence is equal to the angle of reflection; and, second, that the incident ray, the reflected ray, and the normal all lie in the same plane.

When light traveling in air strikes the surface of clear glass, a part of the light will be reflected; the rest will enter the glass. If the incident ray lies on the normal (zero angle of incidence), about 5% of the light will be reflected. As the angle of incidence is increased, the amount of reflection increases. As the angle of incidence approaches 90°, the reflection approaches 100%.

When light traveling in glass strikes an air surface, part of the light will be reflected back into the glass; the rest will enter the air. At zero angle of incidence, about 5% of the light will be reflected back into the glass. As the angle of incidence is increased, the amount of reflection increases rapidly. When the angle of incidence becomes greater than the critical angle, all of the light will be reflected back into the glass; none of it will enter the air. (The critical angle for various types of glass, at an air surface, varies from 37° to 43°.) This property of a glass-air surface, called total internal reflection, is used in many optical instruments. Figure 3E3 shows how the line of sight may be deviated through an angle of 90° by internal reflection at the diagonal face of a right-angle prism.



110.31
Figure 3E3.—Total internal reflection in a prism.

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If the prism in figure 3E3 is rotated (in the plane of the page) through any angle, the angle of incidence will be changed by the same angle. The angle between the incident ray and the reflected ray will therefore be changed by twice that amount.

3E4. REFRACTION

When light passes from air into glass, its speed will decrease. It will resume its original speed when it leaves the glass and enters the air. If a ray of light strikes an air-glass or a glass-air surface at an oblique angle, its change of speed will result in a change of direction. Figure 3E4 shows why this is so.

The diagonal lines in the figure represent the approaching light waves. Since they are coming from a distant source, they are parallel. As each wave enters the glass, various points along the wave front will slow up successively, and as a result the entire wave front will change its angle. Since the direction of movement, shown by the ray, is at right angle to the wave fronts, the light bends as it enters the glass. The opposite effect occurs when the waves leave the glass. Now the various points along the wave successively increase their speed. As a result, the emergent waves are parallel to those that entered the glass. And the emergent ray is parallel to the incident ray, although it has been displaced on one side.

Figure 3E5 illustrates some of the terms used to describe the refraction, or bending, of light. The LAW of refraction states that light bends toward the normal when it passes into a denser medium; it bends away from the normal when it passes into a less dense medium. The exact angle of bending may be easily calculated. It depends on the angle of incidence, and on the optical density of the two media. Optical density is expressed as index of refraction. (The index of refraction of a vacuum is 1; the index of refraction of air is approximately 1. The various types of optical glass range from approximately 1.5 to 1.96.)

When the two glass surfaces are parallel, as in figure 3E4, the emergent ray is parallel to the incident ray. When such elements occur in optical instruments (as, for example, in the end windows of rangefinders), they do not deviate the line of sight. However, if the two glass surfaces are not parallel, the line of sight will be deviated, as in figure 3E6. Thin prisms are used in rangefinders to deviate the line of sight through a small angle.

3E5. IMAGE FORMATION

Figure 3E7 shows the path of parallel rays of light on passing through two prisms mounted

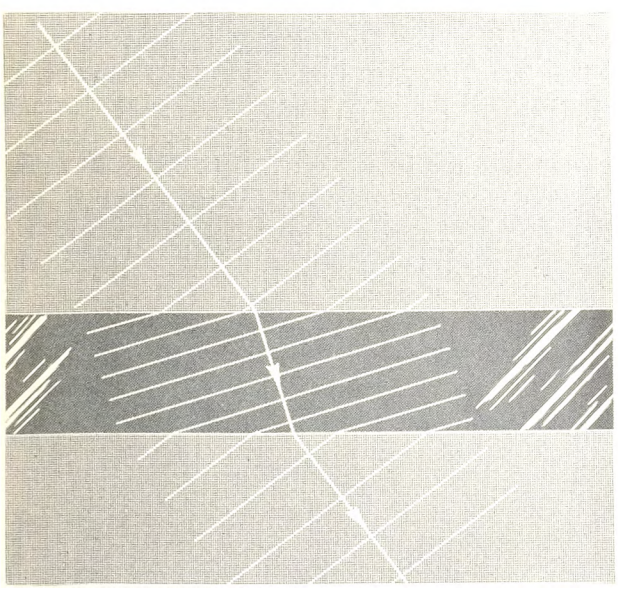

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Figure 3E4.—Path of wave fronts through a sheet of glass.

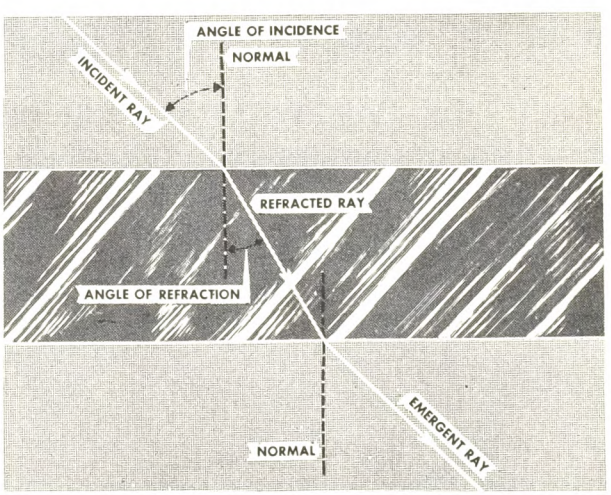

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Figure 3E5.—Terms used to describe the refraction of light.

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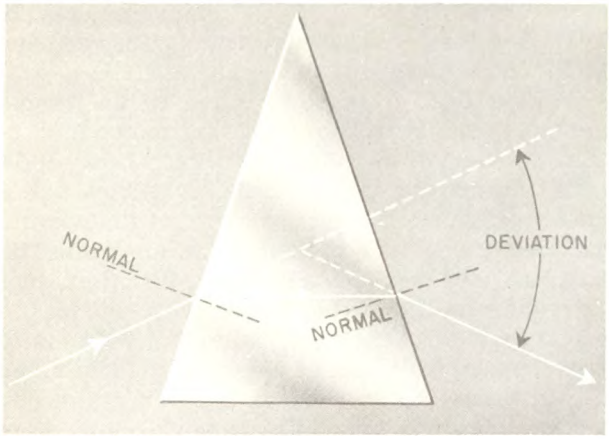

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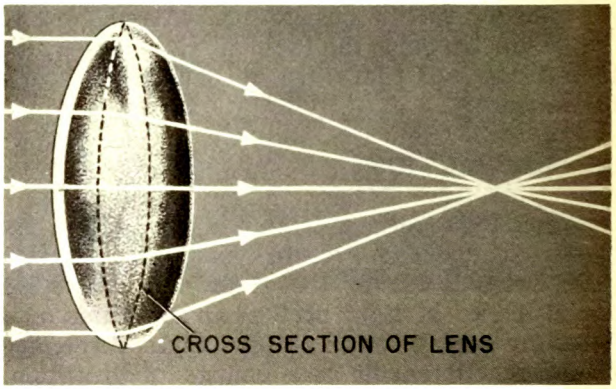
Figure 3E6.—Refraction in a prism.



12.234
Figure 3E8.—Deviation of rays passing through a convergent lens.

base to base. Each ray will be deviated toward the base of the prism it passes through. The upper rays deviate downward, and the lower rays upward. All the rays emerging from the upper prism are parallel, and all the rays emerging from the lower prism are parallel. But if the surfaces of the two prisms in figure 3E7 are rounded off to form a convergent lens, as in figure 3E8, each ray will have a different angle of incidence, and will therefore bend to a different degree. The ray that passes through the center of the lens is normal to both surfaces, and does not bend. Such a ray is said to lie on the optical axis of the lens. The greater the distance from the axis, the greater the angle of incidence at each surface, and the greater the deviation toward the axis. If the lens is perfect, all rays parallel to the axis will meet at a single point, called the focal point of the lens.

Every lens has two focal points, one on each side. The two focal points are equally distant from the lens. The distance from either focal point to the center of the lens is the focal distance, or focal length of the lens.

Figure 3E9 shows three rays of light diverging from a point source, and passing through a convergent lens. (An infinite number of rays strikes the lens, but three suffice to show what happens.) All the rays from A that pass through the lens coverage and meet at point B. Point B is therefore the image of A. Note that B is itself a source of light, since rays diverge from it just as they do from A. If a sheet of paper is held at B, the image may be seen as a bright point on the

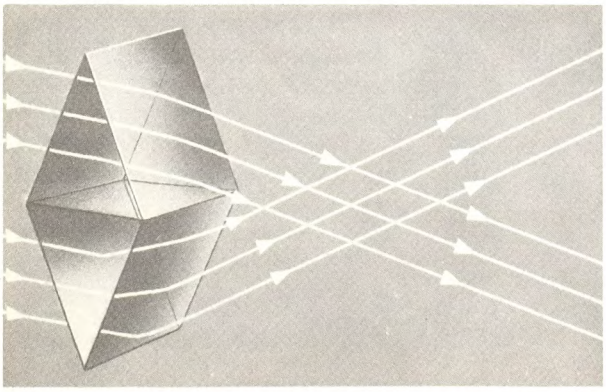


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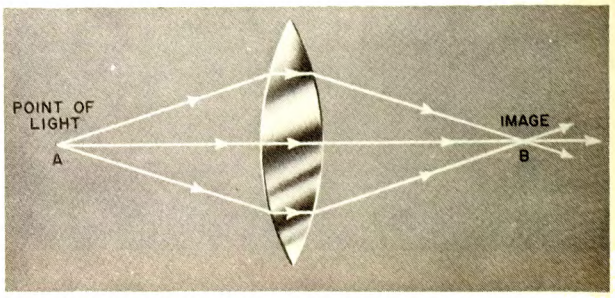
Figure 3E7.—Deviation of rays in two prisms.



110.34
Figure 3E9.—Image of a point.

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paper. If B lies between the lens and the observer's eye, the image may be inspected directly.

In figure 3E9 the distance from point A to the lens is greater than the focal length. If the source were at or closer than the focal point, the rays emerging from the lens would not converge.

A target or other object is visible when it reflects light toward the observer. For each point on the target, a convergent lens will form a corresponding image point behind the lens. These image points together form a real image of the whole target which would appear inverted on a flat sheet of paper held at this location. See figure 3E10.

3E6. VIRTUAL IMAGES

Figure 3E11 shows the path of several rays diverging from the point of an arrow when the arrow lies between the lens and its first focal point. The lens makes the rays less divergent, but does not bring them to a focus. However, an observer on the right side of the lens may see the point (and the rest of the arrow) by looking through the lens. Since the observer is accustomed to assuming that light travels in straight lines, it will appear to him that the rays from the arrow are actually coming from P, and he sees an image of the arrow apparently located at P. However, if a sheet of paper is held at P, no image will be formed on the paper. The arrow image at P is therefore not a real image. No rays actually diverge from the arrow at P, as they do from a real image; they merely appear to. The arrow at point P is said to be a virtual image.

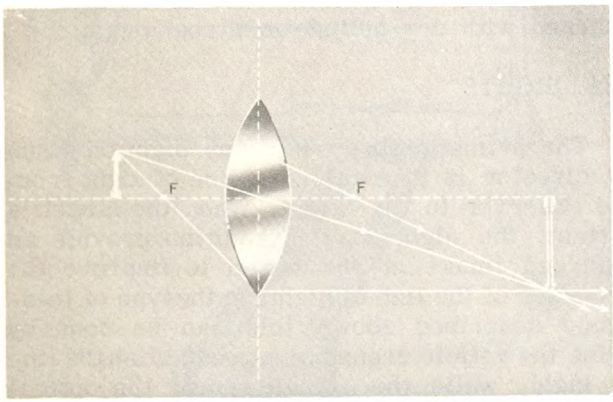

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Figure 3E10.—Formation of a real image by convergent lens.

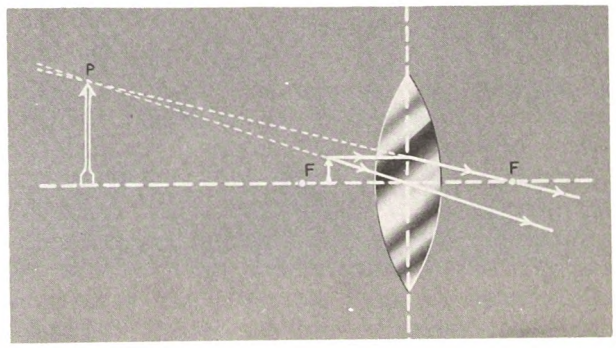

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Figure 3E11.—Formation of a virtual image by a convergent lens.

Note the following characteristics of the virtual image formed by a convergent lens:

1. It is erect. (The real image formed by such a lens is inverted.)
2. It appears to be farther behind the lens than the light source.
3. It is enlarged.

A single convergent lens may be used as a simple magnifying glass by holding it close to the eye. The object distance is adjusted until the image appears in sharp focus when the muscles of the eye are completely relaxed. The object distance will then be equal to the focal length of the lens, and the virtual image will lie at infinity.

3E7. ELEMENTARY TELESCOPES

A telescope provides, to an observer's eye, an enlarged image of a distant object. A single lens cannot be used to provide an enlarged image of a distant object. However, a telescope can be made by using a combination of two or more lenses. The first lens, called the objective, forms a real image of the distant object. The observer may examine the real image through a second lens, called the ocular or eyepiece lens. The ocular serves as a simple magnifying glass. It forms an enlarged virtual image of the real image formed by the objective.

Figure 3E12 shows the path of rays from a distant target through a simple telescope. The drawing shows two rays from the head of the

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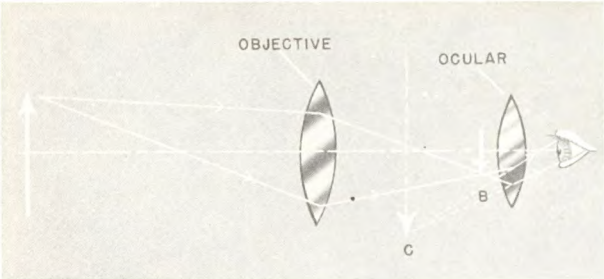

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Figure 3E12.—Simple telescope.

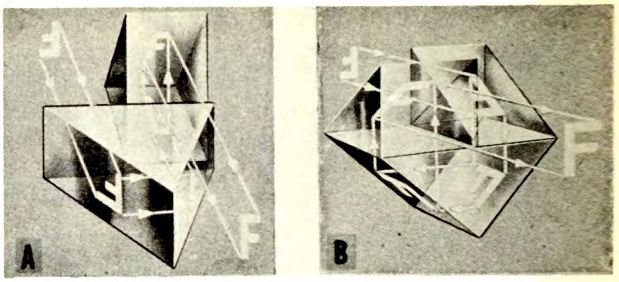

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Figure 3E13.—Prism erecting systems.

arrow converged by the objective to meet at point B. A real, inverted image of the target lies in a vertical plane through B. After crossing at B, the two rays diverge and strike the ocular lens, which makes these rays less divergent. To the observer's eye, the two rays appear to diverge from point C. The virtual image of the target therefore lies in a vertical plane through C. (The ocular is usually adjusted so that this image is at infinity; the drawing shows the image at C only for convenience.) To the observer, the virtual image appears to be considerably larger than the object itself. The telescope therefore forms an enlarged image of the distant object.

In some instruments, the ocular is so mounted that the observer may adjust its distance from the objective to focus on the real image of a close target. In the sight telescope, this focusing adjustment is unnecessary, since the target is always at a considerable distance.

The real image formed by the objective lens and the enlarged virtual image seen by the observer are inverted. To function as a useful fire control instrument, the telescope must present an erect image. One way to do this is to add an erector lens, used as a second objective with the first real image as its target. The erector forms a real image of the first real image and inverts it a second time. The ocular then forms an enlarged, erect, virtual image of the second real image.

A few telescopes, and most binoculars, use prisms to erect the image, by internal reflection at the various prism faces. Figure 3E13 shows typical ways in which prisms may be used to erect an image.

To provide a fixed line of sight through a telescope, a reticle may be added. The reticle is a flat piece of glass on one surface of which suitable reference marks, often two lines (called crosshairs or crosswires) intersecting at a right angle, have been engraved.

In practice, it takes more than four optical elements (objective lens, erector lens, ocular lens, reticle) to make a sight telescope. Additional lenses are necessary to correct the aberrations or distortions of the optical system. Or an individual lens may be constructed of several carefully cemented pieces of glass. In a "simple" telescope, the objective may consist of two or three separate lenses, cemented together. The erector and ocular are each made up of from two to four separate lenses. The spacing of the various elements must be maintained precisely; moisture must be excluded, and the interior parts and cementing compounds must be protected against tampering, corrosion, and other causes of deterioration. All Navy optical equipment is therefore hermetically sealed. Fixed equipment such as gun and director sight telescopes, rangefinders, etc., is in addition charged with dry helium or nitrogen gas.

3E8. SIGHTS

The primary purpose of any sight on a gun or director is to establish a line of sight from the observer to the target. When the target is distant, the sight may in addition provide an enlarged image of the target to improve the accuracy of the line of sight. In the type of telescope described above, this can be done by using the reticle crosshairs to establish the line of sight, while the remainder of the optical system enlarges the target image.

Chapter 5 will explain in detail the geometry of the fire control problem, and the function of the optical sight and the line of sight in it.

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Here let us concentrate on the optical systems used in sights. No specific marks and mods of sight are described here, but we can identify three general types of sight:

1. Simple sights without optical systems.
2. Telescopic sights with fixed optical components.
3. Sights with movable optical components.

SIMPLE SIGHTS WITHOUT OPTICAL SYSTEMS. An example of this is the peep sight used on infantry small-arms weapons, or the ring sight (figure 3E14) installed for emergency use on some antiaircraft gun mounts. The observer looks through the eyepiece. When he has the target in line with the center of the front sight, the line of sight to target is parallel with the gun bore. To provide for ballistic and other fire control corrections, the observer must offset the line of sight so that it diverges from the gun bore by a certain angle. He can judge the amount of offset in this simple sight by using the concentric rings and spokes of the sight instead of the sight's center to align the line of sight to target. Use of this type of sight is restricted to targets at short ranges in emergencies when other methods are not available. Effective use of the sight to direct gunfire requires considerable training, and at best it is not as accurate as other systems.

TELESCOPIC SIGHTS WITH FIXED OPTICAL COMPONENTS. Sights of this type are used in antiaircraft rapid-fire gun mounts, in fire control directors, and in heavy turret mounts. Two typical systems are diagrammed in figure 3E15. The main difference between them is that one has all the elements in a straight line, while the other uses prisms. In the direct system (part A in the figure), the objective lens forms an inverted real image of the target. This image falls on the engraved surface of the crossline lens, or reticle. Between the reticle and the erecting lenses are three color filters and a plain glass filter, so mounted that the operator can bring any one of them into the line of sight. A filter will, under some conditions, increase the contrast of the target image, and decrease glare from sky and water. The erecting lenses erect the target image, and form a real image near the eyepiece of the crosslines superimposed on the target. The sealing window, of plain glass, helps to keep out dirt and moisture. The eyepiece may be moved to focus the image without affecting the seal of the rest of the instrument.

The indirect optical system, shown in part B of figure 3E15, is basically similar. The principal difference is that the line of sight is twice reflected by prisms, so that most of the telescope lies at right angles to the line of

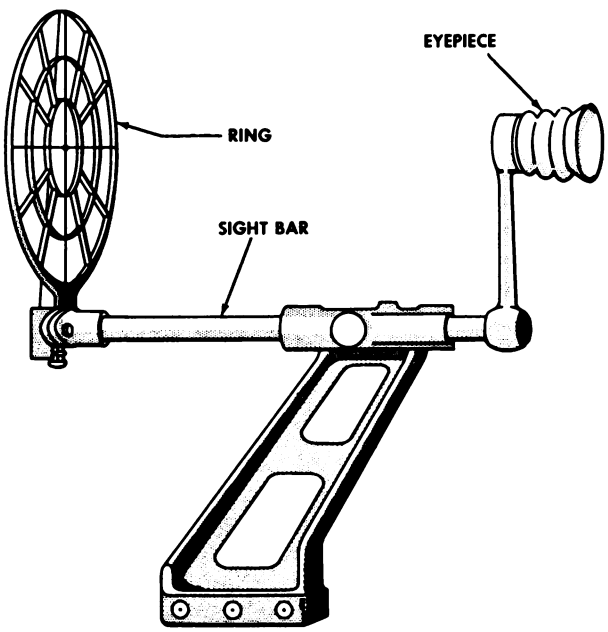

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Figure 3E14.—Open ring sight.

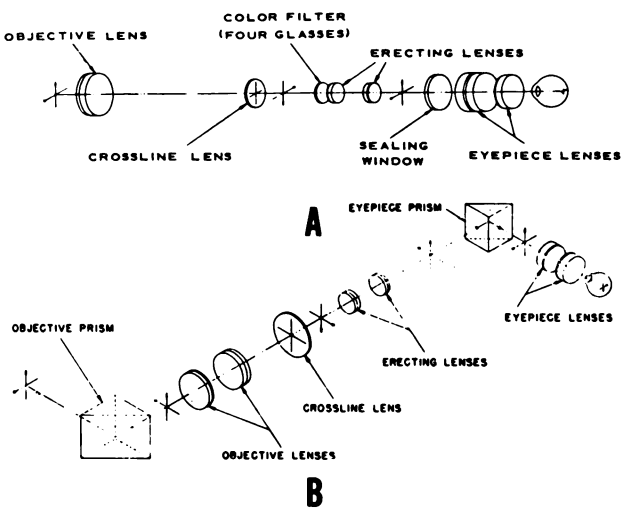

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Figure 3E15.—Optical systems of telescopic sights with fixed optical components. A. Direct (no prisms.); B. Indirect (prismatic).

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sight from gun to target. Two separate objective lenses, or two lenses cemented together, form the first real image. Other varieties of this kind of optical system may use a single prism. To adjust the offset to the gun bore, the telescope is moved as a whole.

SIGHTS WITH MOVABLE OPTICAL COMPONENTS. There are two main varieties of sight with movable optical components.

In one, which is used in heavy antiaircraft gun mounts, the optical system in principle resembles that illustrated in part B of figure 3E14, except that an additional prism as well as the objective or head prism are linked mechanically to a sight setting system on the gun mount. Thus the line of sight can be offset without moving the entire telescope. (Such a system may additionally contain erecting and other prisms.)

In the other variety of sight with movable optical components, shown in figure 3E16, the optical system includes a reflecting glass, a collimating lens, and a lamp. This kind of optical system is used with gyroscopic lead-computing sights, which are explained in chapter 5. The two windows seal the instrument to keep out dust and moisture. The system illustrated here does not magnify the target image. The operator observes the target directly, through the two windows and the clear reflecting glass. The lamp illuminates the reticle, which is located at the focal point of the collimating lens. Rays of light from the reticle are therefore parallel after they pass through the lens and are reflected toward the operator by the reflecting glass.

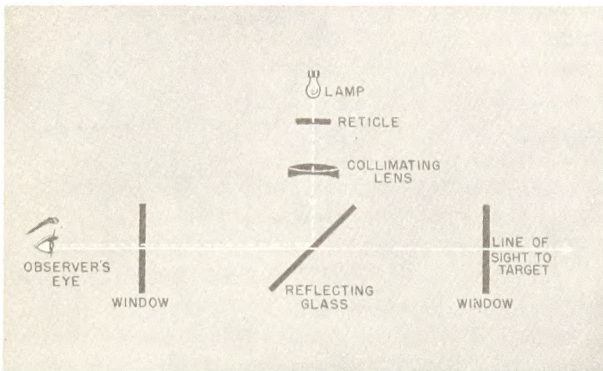

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Figure 3E16.—Optical system for a lead-computing sight. Simplified.

Because these rays are parallel, the reticle image appears to lie at infinity, and the reticle will not change its apparent direction when the operator moves his hand from side to side. The sight's gyroscopic mechanism rotates the reflecting glass so that it will deflect the reticle image as seen by the operator. The operator then trains and elevates the gun mount to keep the reticle on target; this automatically offsets the gun bore as required by the computed solution to the fire control problem.

In another variant of this principle, the reticle image is transmitted through the reflecting glass, while the target image is reflected. The principle remains the same, except that it is the target image rather than the reticle image that is apparently shifted. It is also possible to use two mirrors, one for elevation and one for train, combined with a true telescopic optical system, filters, and an additional device called a "pellicle" (actually a kind of half-mirror) which can reflect a radar scope image to the operator. This arrangement makes it possible to use the sight even when (as in fog or darkness) no optical target image is available.

3E9. RANGEFINDERS

As you will find in chapter 5, one important item of information needed for solving the fire control problem is the range to the target. One way of getting this information is to use an optical rangefinder. Let's briefly discuss the principle of operation of the most used type—the stereoscopic rangefinder. (Another type, not taken up here, is the coincidence rangefinder, which is similar in external appearance, somewhat different in optical principle, and not as versatile.)

The rangefinder consists essentially of a system of optical units assembled in a long, cylindrical tube, mounted in a turret or director, so that only the protruding ends are exposed. On its forward surface, the tube has a window at each end. Through these windows, the operator establishes two separate lines of sight to the target. The distance between the windows is the base length.

The rangefinder determines range by solving a right triangle in which one side (the base length) and two angles are known. Range is one of the unknown sides. In figure 3E17, TPS is the range triangle. PS is the known base length (B) of the rangefinder. The target lies at T; PT

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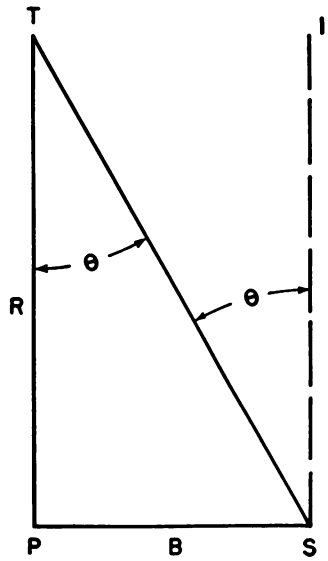

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Figure 3E17.—The range triangle.

is the target range (R). TPS is always a right angle; the line of sight from the left end window is at a right angle to the rangefinder tube axis. The two lines of sight converge and meet at the target, forming angle of convergence θ. SI is an imaginary line parallel to range line PT. Angle TSI is therefore equal to angle of convergence θ. The rangefinder measures the angle of convergence by measuring angle TSI.

Because this is a right triangle, it is apparent that $R = B \cot \theta$. The equation may be solved for R, then, as soon as the angle of convergence has been measured.

A pair of human eyes uses several clues in its perception of relative distance. Of these, the one on which the functioning of the stereoscopic rangefinder depends is convergence, i.e., the sensing of angle θ (fig. 3E18) by the muscular effort required for both eyes to see a single fused image. You can demonstrate this to yourself in exaggerated fashion by first holding your finger a foot in front of your nose, and focusing on it; then, without shifting your line of vision, focusing on an object ten feet or more distant.

The "base length" (or pupil-to-pupil distance) of a pair of human eyes is about 2.75 inches. Beyond a range of about 450 yards or so the lines of sight of the two eyes converge so little that changes in angle θ are too small to

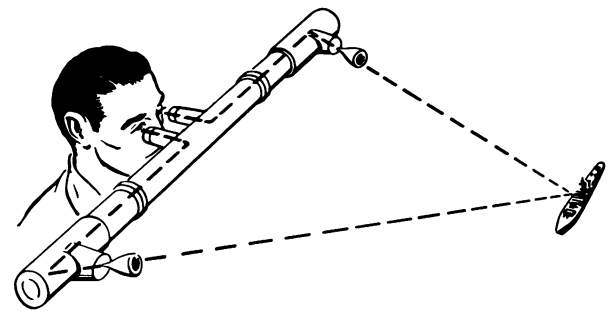

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Figure 3E18.—Function of the rangefinder.

sense. If the base length could be increased, θ could be reliably measured for much longer ranges. In one sense, as shown in figure 3E18 that is what the rangefinder is designed to do.

Figure 3E19, shows in simplified schematic form the optical system of a stereoscopic rangefinder. (Each of the two telescopes contains an erector system, which has been omitted from the drawing for the sake of simplicity.) The diamonds represent the reticle pattern; the arrows represent the two images of the target. Because the apparent angle of convergence of the two reticles is fixed, the reticle pattern appears to lie at a certain fixed distance in space. If the target happens to be at that distance, target and reticle will appear to be equally distant from the observer. If the target's convergence angle differs from the reticle's, the right-hand line of sight to target must be adjusted till they match. To do this, the knob on the right is used to rotate two compensator wedges—thin prisms with sides nearly parallel—through which the light from the target passes. But since they are not parallel, rotating the prisms will deflect the line of sight. This corresponds to changing angle θ (see fig. 3E17).

Figure 3E20 shows the two images seen in the stereoscopic rangefinder eyepice, one for each side of the rangefinder. If the rangefinder operator turns his range knob until the target appears to be at the same range (i.e., has the same convergence angle) as the large central diamond, the range scale will read the actual range to target. The other reticle markings (wander marks) are used in estimating how far from the target projectiles are bursting or falling, and in correcting fire accordingly.

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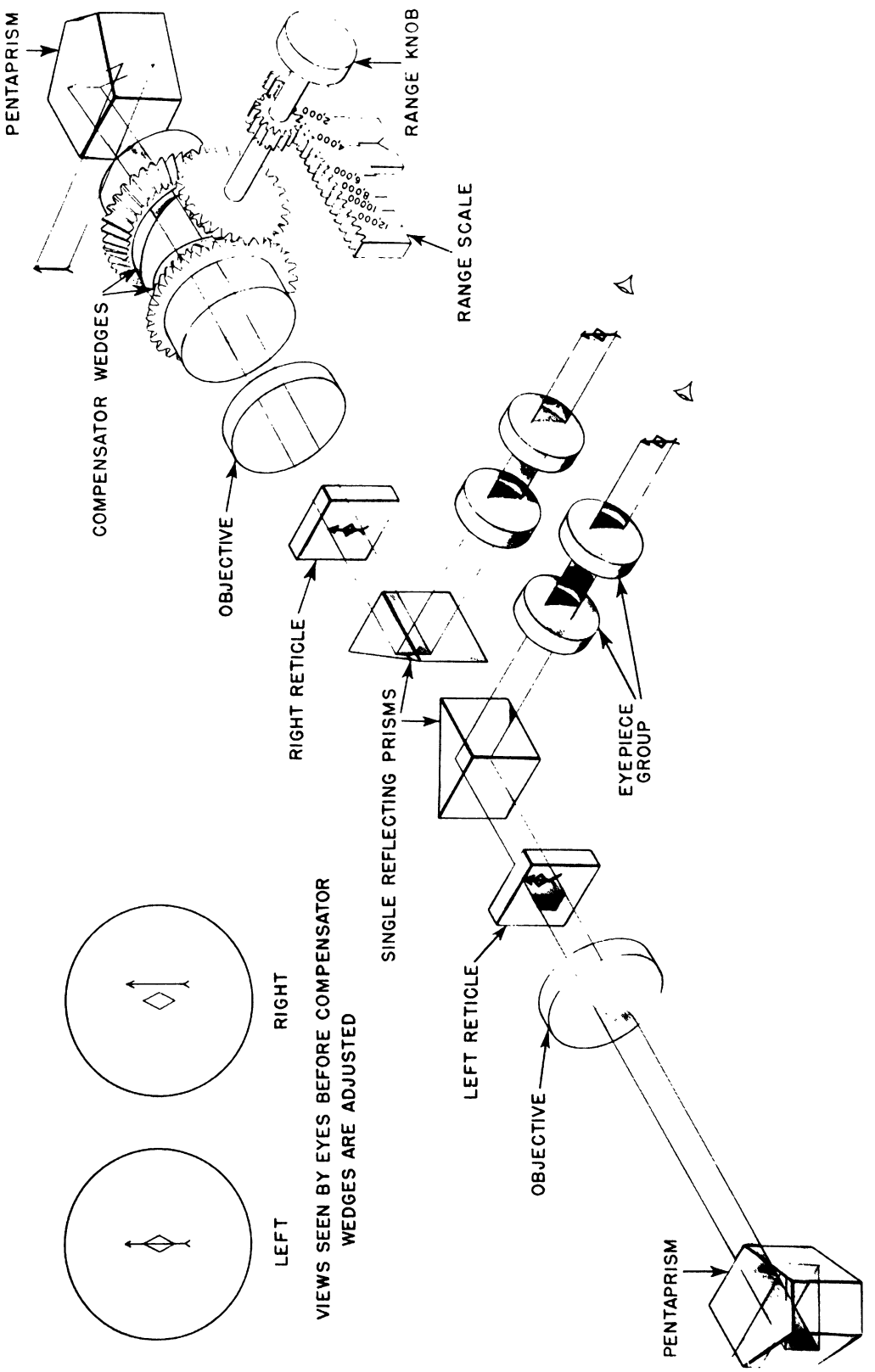

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Figure 3E19.—Elementary stereoscopic rangefinder.

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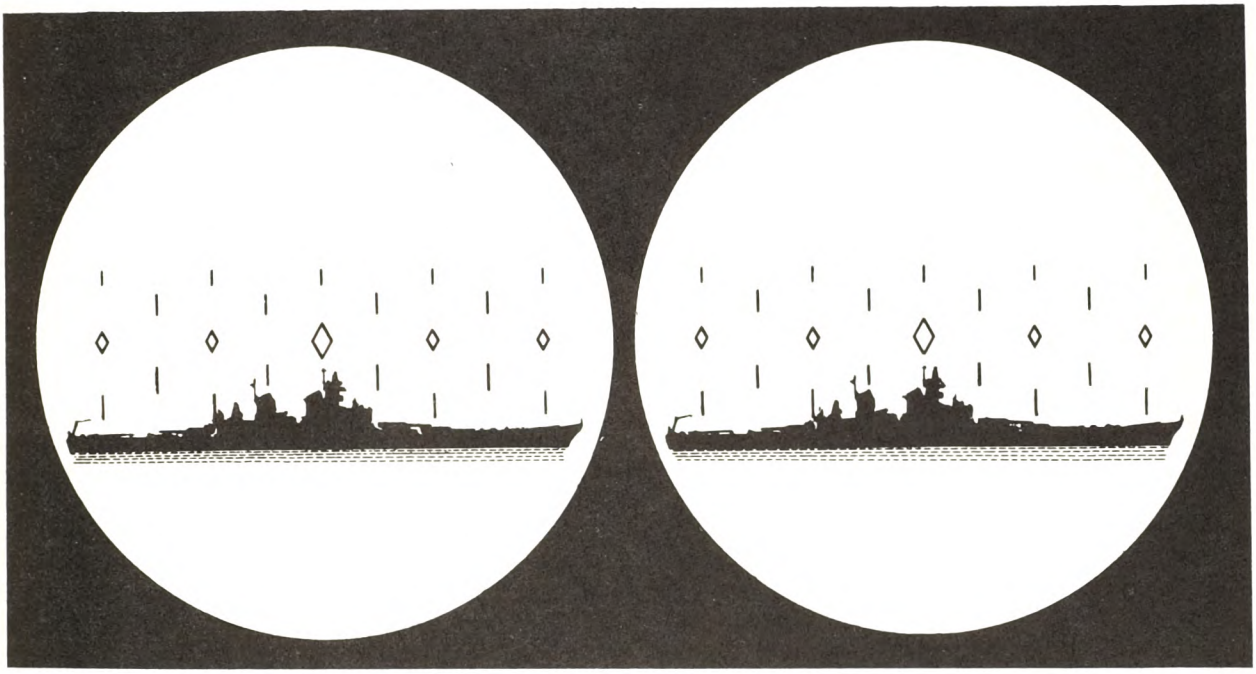

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Figure 3E20.—Reticles and target as seen in stereoscopic rangefinder eyepiece.

F. Elements of Sound

3F1. INTRODUCTION

Sound is the physical cause of your sensation of hearing. Anything that you hear is a sound. But there are also sounds that you cannot hear.

Sound travels in the form of waves. These waves vary in length. A long wave length is heard as a low-pitched sound, a short wave length is heard as a high-pitched sound. A complete wave length is called a cycle. If the sound is below about 20 cycles per second or above 15,000 cycles per second, most people cannot hear it. The range between, which can be heard, is called the audible range and the sounds you hear are known as sonics. Sounds below this range—below 20 cycles—are subsonics. Sounds above this range—above 15,000 cycles—are ultrasonics.

In order to have sound, it is necessary to have a sound source which can vibrate, and a medium to transmit the vibrations. And, for our purposes, it is necessary also to have a detector.

Anything which moves rapidly to and fro, or vibrates and thus disturbs the medium around it, may become a sound source. Bells, radio loudspeaker diaphragms, the human voice, and musical instruments are familiar sound sources.

Sound waves are passed along by the particles of the material through which they travel. Therefore, a material substance, a medium, is necessary to transmit sound waves. A sound medium is any material substance through which sound energy will travel. It may be a gas (such as air), a liquid (water), or a solid (steel). The medium must be something material, or the sound will not be transmitted. Sound will not travel through a vacuum. Most of the time you are mainly concerned with sounds transmitted through air, but in sonar, you are interested in the liquid medium—water.

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Commonly, the detector of sound is the human ear. It receives part of the sound wave energy from the medium, and converts it into an impulse that goes to the brain. Electrical devices like microphones or other transducers can also respond to sound waves and convert them into electrical impulses. (In general, a transducer is any device that converts electrical signals to some other form, or vice versa.) These impulses may be reproduced again as sounds or in some other way—for example, as spots on a cathode-ray tube. Although the human ear can detect as sound only vibrations in the audible range, microphones can be made to detect sounds of any wavelength.

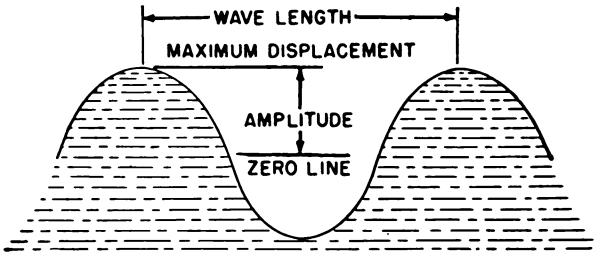

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Figure 3F1.—Transverse water wave.

3F2. CHARACTERISTICS OF WAVES

TRANSVERSE WAVES. If you throw a stone into a quiet pool, series of circular waves will travel away from the disturbance. Figure 3F1 shows such waves diagrammed as though seen in cross section. The water waves are a succession of crests and troughs. Water waves are known as transverse waves because the motion of the water molecules is up and down, at right angle to the direction in which waves are traveling. A cork on the water bobs up and down as the waves pass by.

Although sound waves are not transverse waves, transverse waves (fig. 3F1) like the ripples on a water surface illustrate clearly the notions of amplitude and cycle. Before you threw the stone into the water, the water level (if perfectly undisturbed) was just halfway between the crest and the trough of each wave. The maximum displacement of the surface from this "zero level" is the amplitude of the wave motion. A cycle is one complete double vibration—in this case measured from one crest through zero, the trough, zero again, and the next crest. If you take zero as your reference or starting point, you must include one trough and one crest. If you measure the number of cycles that pass a fixed point in one second, you have the frequency in cycles per second (abbreviated cps).

LONGITUDINAL WAVES. Sound waves are longitudinal or compression waves, set up by some vibrating object such as a sonar transducer. In its forward movement, the vibrating transducer pushes the water particles lying against it, and thus produces an area of compression or high pressure. The backward movement of the transducer produces an area of low pressure, or a rarefaction. This action goes on and on, and sets up a spreading series of compressions and rarefactions. In figure 3F2 the compressions are represented by dark rings. As the sound waves spread out, their energy at the same time is spread through an increasingly large area, and the wave motion at a distance is weaker (i.e., amplitude decreases).

The wavelength is the distance from one point along the wave to the next point of similar compression. The particles of the medium vibrate longitudinally—that is, parallel to the direction in which the sound is propagated.

You already know that the frequency of the wave is the number of cycles per second. In the motion of the sound wave through the medium, the particles of the medium move back and forth in a limited space, passing the wave along, as it were.

Sound waves can go through all gases, liquids, and solids, but not through a vacuum, because there are no particles in a vacuum to be subjected to alternate compression and rarefaction. In different substances and at different temperatures and pressures sound travels at different speeds. In air, the velocity (speed) of sound is about 1,090 feet per second at 32° F. at sea level. For each 1° rise in Fahrenheit temperature, the velocity is increased by 1.1 feet per second. For instance, in air of 72° F., sound travels at the rate of $1{,}090 + (72 - 32) \times 1.1$, or $1{,}090 + 44 = 1{,}134$ feet per second.

In pure water, the velocity of sound is approximately 4,708 feet per second. In sea water, the velocity depends on salt content (salinity), pressure, and temperature. Sound travels at a speed of about 4,800 feet per second in sea water at 39° F.

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3F3. WAVELENGTH=VELOCITY/FREQUENCY

If a sonar transducer vibrates at the rate of 25,000 vibrations per second, and if the temperature is 39° F., the first wave will be 4,800 feet away at the end of the first second. Between the transducer and this wave there will be 25,000 other compressions. Thus the wavelength, that is the distance between points of similar compression, must be 4,800÷25,000, or 0.149 foot, because there are 25,000 compressions extending through a distance of 4,800 feet. The wavelength always can be found if the frequency and the velocity are known, according to the following relationship: $W=\frac{v}{f}$, where W is wavelength. f is frequency, v is velocity.

Example: Suppose that the wavelength is 0.4 foot and the frequency is 12,000 cycles per second. What is the velocity?

$$0.4=\frac{v}{12{,}000}; \text{ or,}$$

$v = 0.4 \times 12{,}000 = 4{,}800$ feet per second.

Similarly, if the wavelength and the velocity are known, the frequency can be found.

$$0.4=\frac{4{,}800}{f}; \text{ or,}$$

$f = 4{,}800 \div 0.4 = 12{,}000$ cycles per second.

3F4. CHARACTERISTICS OF SOUND

As already indicated, the human ear detects vibrations in the audible range as sounds. Concentrate for a moment on what you hear as you read this. No matter how quiet a place you are in, you will hear something. Many of the sounds will have some kind of pattern or organization—for example, speech, music, Morse code, automobile horns, police or fire sirens, ship's whistles, humming motors, etc. These either have patterns that can be interpreted by your mind into specific feelings or thoughts (e.g. speech or Morse code or music), or at least have identifiable pitches or rhythms. Other sounds may be quite without pattern, though not necessarily meaningless—for example, rushing water, radio static, applause, rustling leaves. Such disorganized or patternless sound is, in contrast to "organized" sounds, called "noise." (However, the term "noise" in connection with the problems of communication and signal detection is used in quite a different sense, as will be explained later.)

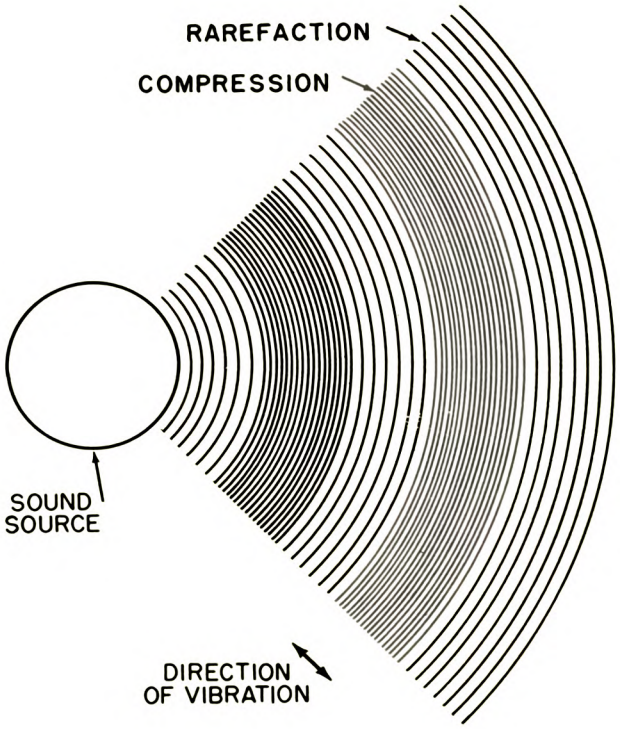

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Figure 3F2.—Longitudinal sound waves.

A musical note has a pattern of regular vibrations. Such a sound has three characteristics—pitch, intensity, and quality.

An object that vibrates at high frequency produces a sound with a high pitch, as, for instance, a police whistle. The slower vibration of a ship's whistle causes a low-pitched sound. When the frequency is low, the sound waves are long; when it is high, the waves are short. Velocity is not affected by pitch.

Intensity (roughly equivalent to loudness) at any selected frequency varies with amplitude. Wavelength and amplitude are independent variables.

Now consider sound quality. As we defined it above, a noise has no identifiable dominating frequency or pitch. It is composed of a large number of frequencies sounding simultaneously. But all sounds of identifiable pitch that you normally hear can be analyzed into more than one frequency. In a note sounded by a musical instrument, the lowest (and principal) frequency is the fundamental, and other, higher, frequencies

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(called harmonics or partials) present in the sound give the sound much of its characteristic color or quality. Quality depends in large degree on just what frequencies are present, and in what proportion. Hence the difference between the sounds produced by a trumpet and a violin both playing the same sustained note. Other factors also affect quality, such as how the sound begins, how it ends, and how it fluctuates in pitch and intensity while sounding. Such considerations make sounds recognizable even when the pitch cannot be identified. Niagara would sound different from a leaky bathroom faucet even with its sound intensity reduced to comparable level. Ability to recognize differences in sound quality is an extremely important characteristic in sonar and hydrophone work.

3F5. CHARACTERISTICS OF SOUND TRANSMISSION IN WATER

As you may have inferred by this time, one of the main reasons for including this section on sound is its importance in the sonar method of submarine detection and location. This is done either by detecting sounds made by submarines in the water, or by radiating sound pulses into the water and analyzing the echoes that return to identify those from submarines. Details concerning sonar gear appear in chapter 10. In this article we discuss briefly the characteristics of sound transmission through water.

When sonar's sound pulse travels through the water, and when the echo returns, they encounter hazards which reduce their strength. Signal strength lost in this manner is known as transmission loss.

ABSORPTION. Some of the sound is absorbed in passing through the water. The amount lost this way depends on the state of the sea. Absorption is high when the winds are great enough to produce white caps and cause a concentration of bubbles in the surface layer of the water. Absorption is also great in wakes and strong currents, such as rip tides. Absorption is greater at high frequencies than at low.

SCATTERING. Sound waves are weakened when they traverse sea water that contains seaweed, silt, animal life, air bubbles, etc., which scatter the sound beam. Scattering reduces echo strength, especially at long range.

REFLECTION AND REVERBERATION. Sonar sound pulses behave somewhat like light in that they can be reflected and refracted. The target can reflect a sound pulse, but so can other underwater objects, and so can the sea bottom and the sea surface ("total reflection" much like that of light in glass, as described in section E of this chapter). The combined echoes from such disturbances are called reverberations. Since they are reflected from various ranges, they seem to be a continuous sound which is stronger at first and gradually fades away. Reverberations from nearby points may be so loud that they interfere with the returning echo from a target.

REFRACTION. Refraction can distort the path of the sound pulse in the water. Sound speed varies with medium density, and this can cause bending of a "ray" of sound much as it bends a ray of light. This effect is described in further detail in chapter 10.

3F6. SIGNAL-TO-NOISE RATIO AND SOUND PERCEPTION

It is no news that when some one is talking to you in a noisy room it is more difficult to hear him than when the room is quiet. To make himself understood, the speaker may turn his face directly toward you, or move closer to you, or talk louder, or eliminate or tone down the source of noise. So far as your own sensing of his voice is concerned, all of these boil down to one thing: He is increasing the strength of his signal relative to that of the disturbing noise, or increasing the signal-to-noise ratio.

In communication work and in sound detection you will find that this ratio is extremely important. The ratio is expressed in decibels (abbreviated db). Ten decibels make a bel, a large unit named after the inventor of the telephone, Alexander Graham Bell. A decibel is a logarithmic expression of the difference in level or intensity between a "reference" signal and another signal, or between a signal and noise or interference. The intensity level of signal A is n decibels higher than that of reference signal B if

$$n = 10 \log A/B$$

Under laboratory conditions (i.e., completely quiet room, with no sound-reflecting surfaces, use of "pure" tones—fundamentals with no harmonics—of constant pitch in the most sensitive range of the human ear, etc.) 1 decibel is the minimum difference in sound level that the average observer can detect. As a practical matter, under fairly quiet (not laboratory) conditions, an attentive, acute observer cannot

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detect differences in level of such sounds as speech and music much less than 3db—and a signal 3 db higher in intensity than a second signal has twice the sound energy of the second sound.

When an audible signal is equal in level to the noise or interference accompanying it, and is of similar characteristics to the interference or noise as regards frequency, pulse rate (if any), etc., the human ear cannot distinguish it from the noise. (In this sense, "noise" can include not only unorganized sounds that we previously, in article 3F4, defined as noise, but also other unwanted signals such as speech, even though such signals are not noise in the sense of article 3F4. From this point of view, noise is any sound that interferes with reception of the desired signal.) Sometimes, if the noise is in a different frequency range from the desired signal, comes from a different direction, or is different in some other fundamental characteristic, it may be possible to filter it out to some degree mechanically, electrically, or by "selective listening." Thus, you may be able to communicate on the phone through a loud high-pitched squeal or low-pitched hum, but it's much harder to do this if there's another lively conversation on the wire at the same time.

In general, however, there must be a sizable difference in level between signal and noise for effective reception. In this connection, "sizable difference in level" doesn't mean a 50% difference, or even a 100% difference. You simply cannot perceive satisfactorily a signal that is only twice as loud as the accompanying noise (i.e., a signal at 3 db level). Bear in mind that in a quiet room ordinary speech is about 60 db higher in level than barely audible background noise, and this represents a signal-to-noise ratio of about one million to one. Under excellent radio conditions, the signal may be 30 db above the interference ("static") level; this signal-to-noise ratio is about 1,000 to one. When the signal-to-noise ratio in sonar reception is 10:1 (i.e., 10 db), only a well-trained Sonarman with excellent hearing can reliably get the signal above the interference. A Sonarman with less training won't get the signal unless it's at a level of 15 db. The lowest level signal that any Sonarman has ever been able to perceive is on the order of 5 db (three times as loud as the interference).

These ratios apply also to radio communication. The signal-to-noise ratio concept (and even measurement in db) has been applied even to video (visual) signal presentation and in general to other areas in which power levels must be compared, or intelligible signal reception through "noise" (audible, visible, or electrical) must be measured.

The human ear's sensitivity differs throughout its frequency range, and this characteristic is utilized in sonar to provide for optimum performance. Although sonar pulses and echoes are often in the ultrasonic part of the sound frequency spectrum, sonar equipment converts the received signal to a selected frequency, usually in the range of 600 to 1,000 cps, where the human ear is at its best with respect to sensitivity, pitch discrimination, and ability to recognize an echo by its characteristic quality.

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CHAPTER 4

EXPLOSIVES, AMMUNITION, AND GUNS

A. General

4A1. SCOPE OF THIS CHAPTER

This chapter is designed to introduce to the student the principles of those naval weapons that depend for their functioning on the use of chemical explosives and propellants. These include guns and their projectiles, torpedo and rocket warheads, and explosive trains in mines, bombs, and depth charges.

The next section of this chapter discusses the characteristics and nomenclature of chemical explosives in general. (Since much of the second volume of this course is devoted to nuclear weapons, such weapons and the principles of nuclear reactions are not taken up here.) The section following that discusses gun projectiles and weapons other than guns. The concluding sections of the chapter deal with guns.

As the preceding chapter in this course brought out, many words that have precise technical meanings when used in specific fields of science and technology have much broader, and sometimes quite different, meanings when they appear in more general contexts. This is worth repeating here because in this chapter and throughout the remainder of this course you will continually encounter words of this kind, such as range, booster, explosive, and detonate. Unless the context unmistakably indicates otherwise, these words are used in this course in their strict senses, as defined in this course and in related reference materials.

Note also that there have been some relatively recent changes in nomenclature and definitions in the subject matter of this chapter. Since these changes have probably not yet been incorporated into all the older technical materials you will encounter on the subject, the older usages are indicated where appropriate, for your convenience. However, make it a habit to avoid using older terminology and colloquialisms; restrict yourself to the up-to-date vocabulary of the naval officer's profession when discussing technical matters of this kind.

B. Explosives and Related Materials

4B1. DEFINITIONS

Broadly, if used without further qualification, the term explosive includes all those substances that, when initiated (by spark, friction, shock, or other means), undergo a rapid chemical reaction that results in the formation of gases and the release of a great amount of stored energy. The reaction is accompanied by high pressure and usually by high heat. In this sense the term explosive is broad enough to include all the substances described in this section.

Note that this usage of the term, though broad, excludes as explosive substances such things as high-pressure steam which may burst (or colloquially "explode") a boiler, or high-pressure gas that under certain circumstances may rupture its container.

In strictly technical usage, however, the term explosive includes only those substances that detonate. This means that when their reaction is initiated they produce a sharp shock wave that releases all the stored energy almost instantaneously. As it appears hereafter in this course, the

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term explosive will be used in this strict sense only (when applied to chemical explosives).

Explosives include two classes—primary explosives and high explosives. Primary explosives are particularly sensitive to shock, heat, or similar stimuli. They are therefore used in initiating devices (such as the fuzes described later in this chapter) to set off chemical reactions in less highly sensitive substances. High explosives are comparatively insensitive to shock and heat. They are detonated by the initiating devices previously mentioned. High explosives are used as burster charges to damage the target by blast, by heat, or by fragments from the container (e.g., projectile body, bomb case, etc.).

Propelling charges or propellants are explosive-like substances that burn rather than detonate. The rate of burning, though rapid compared with the burning of common combustible materials, is much slower than detonation. (For example, a high explosive like TNT detonates at the rate of several thousand yards per second; a typical gun propellant burns at a rate measured in inches per second.) An important characteristic of any propellant's burning rate is that under a given set of conditions it will always be the same. Propellant burning rate is controllable, and, in contrast to explosives which detonate rather than burn, can be predetermined within close limits by adjusting the propellant's composition, the conditions of burning, and related factors.

Note that the distinction between explosives and propellants rests as much on the conditions under which they react as upon differences in composition. Explosives that normally detonate can be made to burn, under certain conditions not characteristic of their usual application; conversely, under abnormal conditions, propellants can be made to detonate. To underline this point, consider gasoline vapor mixed with air. Under optimum conditions in an internal combustion engine cylinder, this mixture burns like a propellant to produce useful thrust. Under less favorable conditions it detonates with damaging impact, evidenced by a characteristic "knock" or "ping."

Propellants may be liquids or solids (but such fuels as gasoline are not propellants in the sense defined in this article). When a propellant burns, it produces hot high-pressure gas. In such applications as rockets and JATO units the thrust produced by the gas as it escapes through a suitably shaped nozzle is used to drive a load (i.e., the rocket head or aircraft). In such applications as mortars, guns, and depth-charge projectors the thrust produced by the gas directly propels the projectile.

With specific reference to propellants used in guns, the term cool propellant is used to describe one that burns at a relatively low temperature. This is an advantageous characteristic.

For reasons which will become evident later in this course when explosive ordnance is described, practically all explosive and propellent units contain two or more explosives and explosive devices, arranged so that they function in sequence when the unit explodes. This series of stages is called an explosive or propellent train (fig. 4B1).

In explosive devices like bombs and gun projectiles, the explosive train typically consists of an initiating device called a detonator, containing a relatively small quantity of primary explosive; a booster which contains a larger quantity of less sensitive explosive and is set off by the functioning of the detonator; the booster detonates the burster, which is the main charge of the device and in general is much less sensitive than the preceding stages. In specific devices there are variations on this basic sequence of stages; in small gun projectiles the

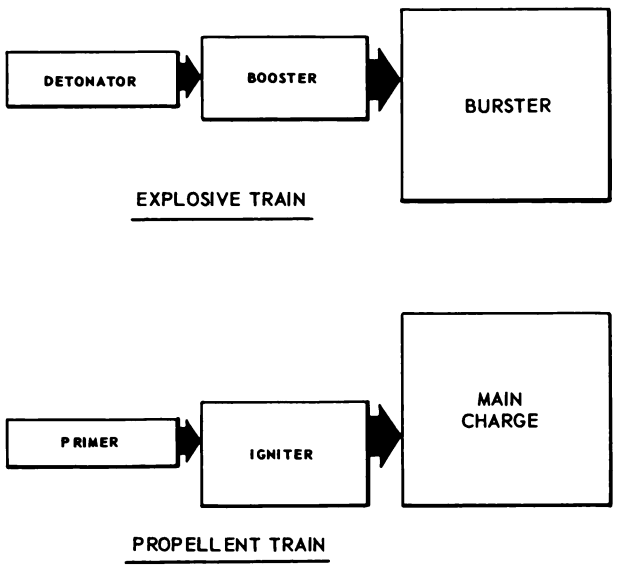

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Figure 4B1.—Explosive and propellent trains. Simplified schematic.

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explosive train is simpler, with the booster omitted or combined with the initiating device, while large aircraft bombs and mines have additional auxiliary stages.

Propelling charges use similar trains. The initiating stage is called a primer, and produces a hot flame which sets off the next stage, called the igniter. The igniter in turn sets off the main charge.

PYROTECHNICS are chemical devices that produce light for illumination or signaling, or smoke for signaling, and may utilize explosive or propellent substances in performing their functions. Specific pyrotechnic devices used by the Navy are described later in this chapter.

CHEMICAL AGENTS include a variety of gaseous, liquid, or solid substances used for signaling, for screening, for harassing or attacking the enemy by asphyxiation or other chemical damage to personnel, or for burning enemy targets. The three main groups of chemical agents are war gases, smokes, and incendiaries. Further detail on specific chemical warfare devices and substances appears later in this chapter.

DEMOLITION AGENTS are explosives issued and used in specialized demolition equipment other than ammunition. Certain military explosives like TNT are used both in ammunition and in demolition equipment, but in general the requirements of an explosive for demolition and for use in ammunition are not the same, and many explosives, such as Explosive D and nitrostarch respectively, are used either in ammunition, or in demolition equipment, but not in both. The Navy uses demolition explosives in such work as destruction of obstacles or hazards to navigation (such as the sinking of floating hulks), blasting preparatory to construction, destruction of classified equipment if capture by the enemy is imminent, or destruction of designated enemy targets by specially trained personnel such as frogmen.

OUTMODED TERMS. Older textbooks on ordnance, and even current texts directed to supply personnel and activities, use the expression low explosive to include the various explosive-like substances whose reaction is a burning process rather than a detonation. The term is no longer correct in military context. It is retained in shipping instructions and similar documents because the law still recognizes it as a valid blanket term covering propellants and pyrotechnics.

4B2. BASIC CHEMISTRY OF EXPLOSIVES AND PROPELLANTS

Explosive substances include a large number of chemical compounds and mixtures. Relatively few of these have the characteristics that make them practical for military use, and the discussion in this chapter applies only to those actually used in the Navy.

Most explosives and propellants used by the Navy are organic compounds or mixtures of explosive organic compounds, most of them based on nitrogen. (Hence the presence of "nitro" in the chemical names of most Navy explosives.) A few are inorganic compounds (the chief example is lead azide, used as the sensitive initiator in detonators). One explosive used in the Navy is a simple mechanical mixture (not a chemical compound) of chemicals which individually are not explosives—this is black powder.

It is important to note the distinction between mixtures and chemical compounds. A mixture consists of two or more distinct substances, either chemical elements or chemical compounds, which may be mixed in various proportions as described. The components in a mixture (of solids) can always be identified individually, even though a microscope or microscopic methods may be necessary to do it; no matter how fine the components may be ground and how thoroughly they may be conglomerated, the mixture cannot be truly homogeneous. In a chemical compound, on the other hand, (1) the substance (if pure) is always homogeneous down to the point where it is broken up into its constituent chemical elements; (2) the components, when isolated, are invariably chemical elements; and (3) the constituents are always present in exactly the same proportions.

Broadly, two kinds of chemical reactions account for the functioning of both propellants and explosives. One is combustion—the combination of oxygen with other atoms or atomic groups, with the accompanying release of energy. The other is a molecular breakdown or disintegration (followed by some recombination) of the relatively unstable nitrogen compounds that, as mentioned above, make up most Navy explosives and propellants.

In propellants, much of the energy developed by the reaction characteristically comes from oxidation. No significant proportion of the oxygen comes from the atmosphere. In black powder, the oxygen comes from potassium or sodium nitrate, which yields oxygen when heated; the

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Figure 4B2.—Smokeless powder grains (caliber .30 to 16"/50); the two white grains are SPCG powder.

oxygen combines with the other two components of the mixture (charcoal and sulfur). In other propellants, the oxygen is part of the original composition, and recombines with other elements when the composition breaks up.

In high explosives, oxidation is not so important a feature of the reaction, though it is usually present. The important energy source is in the breakup of the chemical bonds of the original composition and the recombination of the elements into simpler compounds.

The products of detonation and burning (in explosives and propellants respectively) include the usual products of complete combustion (e.g., carbon dioxide, water vapor), products of incomplete combustion (e.g., carbon monoxide, free hydrogen), products of molecular breakdown and partial recombination (e.g., free nitrogen, oxides of nitrogen, methane, hydrogen cyanide), and unburned residues of the original composition. Some of these products are harmless, some are suffocating, some are combustible or even explosive, and some are dangerous poisons even in fairly low concentrations. These are dangerous substances, particularly in enclosed spaces (where, for example, a high-explosive-loaded projectile may have burst). They are also dangerous in enclosed gun mounts, which are therefore fitted with gas-expelling devices to eliminate them. When such gases are not promptly expelled they may ignite while the gun is being reloaded, causing a burst of flame inside the mount called a flareback.

4B3. CHARACTERISTICS OF EXPLOSIVE AND PROPELLANT REACTIONS

VELOCITY. An explosive reaction differs from propellent reaction in its velocity. The velocity of combustion of explosives and propellants may vary within rather wide limits, depending upon the type of substance and upon its physical state. The burning rate of colloidal cellulose nitrate powders used as propellants in modern guns is in the order of 24 centimeters per second and up at average gun pressures. The velocity of reaction of high explosives ranges from about 2,000 to 8,500 meters per second.

HEAT. An explosive reaction is always accompanied by the rapid liberation of heat. The amount of heat represents the energy of the explosive and hence its potentiality for doing work. The quantity of heat given off by an explosive or propellent reaction is not as large as is popularly supposed. A pound of coal, for example, yields five times as much heat as a pound of nitroglycerine. However, coal cannot be used as an explosive, because it fails to liberate heat with sufficient rapidity, and because it does not incorporate an oxidizing agent.

GASES. The main material products (as distinct from energy products) of explosive or propellent reactions are hot gases and a small amount of solid residue. The pressure characteristics of the gases evolved are discussed below; their composition was discussed in the preceding article. In gun barrels, propellent gases have an additional erosive effect, which contributes significantly to the wear of the gun bore. The effects of such wear on gun performance are taken up in further detail later in this chapter, in the sections on guns.

PRESSURE AND SHOCK WAVE. The high pressure accompanying a propellent or explosive reaction is due to the formation of gases which are expanded by the heat liberated in the reaction. The work which the reaction is capable

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of performing depends upon the volume of the gases and the amount of heat liberated. The maximum pressure developed and the way in which the energy of the explosion is applied depend further upon the velocity of the reaction. When the reaction proceeds at a low velocity, the gases receive heat while being evolved, and the maximum pressure is attained comparatively late in the reaction. If, in the explosion of another substance, the same volume of gas is produced and the same amount of heat is liberated, but at a greater velocity, the maximum pressure will be reached sooner and will be quantitatively greater. However, disregarding heat losses, the work done will be equal.

The rapidity with which an explosive develops its maximum pressure determines its brisance. A brisant explosive is one in which the maximum pressure is attained so rapidly that its shock wave shatters material surrounding it.

4B4. INITIATION OF EXPLOSIVE AND PROPELLENT REACTIONS

Explosive and propellent reactions are initiated by the application of some stimulus which provides energy required to get the reaction started. In general, propellent substances are commonly initiated by heat. The resulting reaction is a burning process, which occurs on the exposed surfaces of the substance and progresses through the mass as each layer is consumed. However, some high explosives will react when sufficient heat is applied, especially if heat is applied suddenly throughout the mass. Initiation by percussion (direct blow), or by friction, is a form of initiation by heat derived from the energy of the blow or friction.

High explosives, such as the main charges of mines or torpedoes, in general require the sudden application of a strong shock or detonation to initiate the explosive reaction. This detonation is usually obtained by exploding a smaller charge of a more sensitive high explosive in contact with or close to the main charge.

Detonation of an explosive mass can also be transmitted to other high explosives in the vicinity, without actual contact. The explosion resulting is said to be initiated by influence, and is called a sympathetic explosion. When this happens with mines or depth charges that are located too close together in the water, the phenomenon is called countermining.

The amount of energy necessary to initiate the reaction is the measure of the sensitivity of the explosive or propellant. Sensitivity is important in selecting an explosive for a particular purpose. For example, the explosive in an armor-piercing projectile must be relatively insensitive or the shock of impact will detonate it before penetration. Too much sensitivity is also undesirable because minor shocks or temperature variations incident to normal handling would initiate the reaction.

Sensitivity has little relation to the power developed by a given weight of explosive. TNT, for example, is quite insensitive, but is pound for pound a much more powerful explosive than mercury fulminate, an initiating compound of great sensitivity.

4B5. CLASSIFICATION OF NAVY EXPLOSIVE AND PROPELLANTS BY USE

In the remainder of this section, the characteristics of individual chemical explosives and propellants now in use in the Navy will be described. These are arranged in the following classification based in each case on their principal use:

1. PROPELLANTS. Propellants are used to propel projectiles from guns, to propel rockets, launch torpedoes, launch depth charges from projectors, and catapult aircraft. Examples are smokeless powder, ballistite, Cordite, and black powder. Figure 4B2 shows smokeless powder grains of various sizes.

2. HIGH EXPLOSIVES. Explosives of this classification are all employed to create damage to the target under attack. They are used alone or as part of the explosive charge in mines, bombs, depth charges, and torpedo war heads, and in projectiles as a burster charge. There is a wide variety in this category, but the more common examples are RDX, TNT, and tetryl.

3. PRIMARY (INITIATING) EXPLOSIVES. The initiation of an explosive reaction requires the application of energy in some form. Propellants are commonly ignited by the application of flame, while explosives are set off by a severe shock. Many primary explosives can be used for initiating either propellants or explosives, because they produce both a flame and a shock when exploded.

A PRIMER is used to initiate the burning of a propellent explosive. A simple primer consists of a small amount of lead azide and a

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small charge of black powder. When fired, the primer produces the flame required to ignite the next component in the train.

A DETONATOR is used to initiate the reaction of a high (disrupting) explosive. It may consist of a charge of lead azide or lead styphnate, either alone or with granular TNT or tetryl in a container. When fired, the detonator produces the shock necessary to initiate the explosive reaction.

4. AUXILIARY EXPLOSIVES. Large propellent charges and relatively insensitive high explosives require an intermediate charge, so that the increased flame or shock will ensure reaction of the main explosive charge. This auxiliary, when used with propellants, is called an ignition charge. It consists of a quantity of flame-producing black powder. The auxiliary explosive used with high explosives is called a booster. It consists of a quantity of more sensitive high explosive, such as tetryl or granular TNT.

4B6. PROPELLANTS

The primary function of a propellant is to produce gases under pressure which can be used to develop a propulsive thrust. This gas pressure must be controlled to avoid exceeding the strength of the container in which it is produced (e.g., guns, torpedo tubes, and depth charge projectors).

Any explosive would serve for propellent purposes if the velocity of explosion could be controlled. Investigations of this problem led to the development of today's smokeless powder. Nitrated cotton (pyrocotton), the main constituent of smokeless powder, is itself a high explosive entirely unsuitable as a propellant. It is combined with an ether-alcohol mixture to control its burning rate.

Smokeless powders are now used almost universally for propellent charges. For military purposes (especially for weapons larger than small arms) there are three main classes: (1) single-base, (2) double-base, and (3) multi- or triple-base powders.

In single-base powders, cellulose nitrates (nitro-cellulose) form the only explosive ingredient. Other materials in single-base powders are included for suitable form, desired burning characteristics, and stability.

Double- or multi-base powders include nitroglycerin to assist in dissolving the nitrocellulose during manufacture, as well as to add to the explosive qualities. Single-base nitrocellulose powders have lower burning temperatures and cause less wear in the gun bore than double-base powders. Present multi-base powders, with a large proportion of the "cool"-burning explosive nitroguanidine, produce maximum temperatures comparable to those of single-base powders.

Propellants for present-day U.S. Navy guns larger than small arms are composed either of single-based or multi- (triple-) based powder. Double-based powders are used as rocket propellants.

SINGLE-BASE SMOKELESS POWDER. This type of powder is used by the U.S. Navy as a propellant in guns 20-mm and larger. It is a uniform ether-alcohol colloid of purified nitrocellulose, plus a small amount of diphenylamine as a stabilizer to retard deterioration of the powder. The grains are cylinders about four to five times as long as their diameters. Larger grains burn more slowly and are used for larger calibers. Figure 4B2 shows the range of sizes. Small grains have 1 longitudinal hole; larger grains have 7. The number and size of holes determines the burning area of the grain (in addition to its ends and convex surfaces) and therefore its burning rate; these have been carefully calculated for each caliber. The grains have a hard, smooth finish, and have much the same texture as horn. Newly manufactured grains are generally translucent and amber. As the powder ages it darkens to opaque dark brown, then black. These changes do not, however, indicate any loss of stability.

Smokeless powder deteriorates in two ways, and particularly in the presence of moisture. First, it decomposes slowly in storage because it is not entirely stable chemically, and eventually will burn spontaneously if decomposition is allowed to run its course. The decomposition products include nitrogen oxides which tend to form acids, thus facilitating further decomposition. Diphenylamine is slightly alkaline in effect, and neutralizes the acid products. This doesn't prevent further decomposition, but prevents the process from accelerating. Short of the extreme of spontaneous combustion, this chemical deterioration does not make the powder dangerous to use. Its principal effect is to weaken the powder slightly, since some of the decomposition that should have taken place in the gun has taken place slowly in the magazine, and the powder therefore cannot produce as much heat energy.

The second type of deterioration is loss of volatile components (ether and alcohol). These

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tend to evaporate if the powder is in the open. A loss of volatiles increases the burning speed of the powder; severe increase in burning speed will cause the powder to develop excessive pressures in the gun when it is fired. Thus loss of volatiles can make the powder ballistically dangerous.

MULTI-BASE POWDER. Multi- or triple-base powder is used in many calibers of guns. It is commonly called Cordite N or SPCG and is composed of four principal ingredients—nitrocellulose (19 percent), nitroglycerine (a little under 19 percent), nitroguanidine (55 percent), and a stabilizer called carbamite or ethyl centralite (a little over 7 percent). Of these 4, the first 3 are explosives. A small amount of potassium sulfate may be added as a flash inhibitor. In some calibers other minor ingredients may be added.

Multi-base powder grains resemble pyro powder grains in size and shape. They have smooth, chalk-white surfaces. After considerable time in storage, the surface color may tend to yellow, but this is not a sign of deterioration.

Multi-base powders are far more stable in storage than equivalent pyro powder, because of relatively low nitrocellulose content, small content of volatiles, and low hygroscopicity. They are more suitable as gun propellants than double-base powder (described below); gases produced by a multi-base powder with nitroguanidine are much less erosive than those of double-base powder. Multi-base powders also are cheap to produce, have little residue after burning, and are relatively insensitive to high temperatures in stowage.

STORING GUN PROPELLANTS. In storage, smokeless powder must be protected against high temperatures, and sealed to prevent entrance of moisture and loss of volatiles. To protect against high temperatures, all magazines in which ammunition containing smokeless powder is stored must be adequately insulated and ventilated, and if necessary refrigerated. Moreover, recording or maximum-minimum thermometers are installed and read daily to verify that the ammunition is uniformly maintained at the lowest practicable temperatures. To protect against entrance of moisture and to prevent excessive loss of volatiles, ammunition containing smokeless powder is kept in sealed tanks or equivalent sealed containers. The tanks are not expendable; they must be periodically inspected and repaired if necessary. They must not be opened when loaded except for inspection or if the ammunition is to be used.

SOLID ROCKET PROPELLANTS. The stream of hot gases that propels a rocket is produced by chemical reactions; the fuel may be either solid or liquid. In this chapter we are concerned only with propellants used in ballistic rockets (i.e., those that do not incorporate systems for guidance after launching). Propellants used only in guided or ballistic missile propulsion are taken up in chapter 4 of Principles of Guided Missiles and Nuclear Weapons, NavPers 10784-A.

Solid rocket propellants are double-base compositions with added ingredients for plasticizing, control of burning rate, and reduction of flash. Gas pressure during burning is about one-tenth of that in a gun barrel, and erosion effect is not important in this application.

A typical propellant grain is made up of a composition identified as Type N-2 (JPN). Its main ingredients are nitrocellulose (slightly over 51 percent) and nitroglycerine (a little less than 43 percent). It also contains two plasticizers for homogeneity of composition, stabilizer (ethyl centralite), potassium sulfate to reduce flash, and carbon black to control burning rate. Depending on the particular rocket motor in which it is to be used, a grain is an extrusion of either cruciform (cross-shaped) or hollow cylindrical cross section, machined in a special lathe to the dimensions required for mounting. Single extruded rocket propellant grains range up to 60 inches in length and 6 inches in diameter. Larger grains for other applications may be cast rather than extruded.

From 1 to 4 gains of ballistite propellant are used as the propelling charge in a rocket motor. The grains are designed to burn at a uniform rate to provide uniform thrust during burning. In cruciform grains with suitable plastic inhibitor strips, the burning area, and hence the rate of gas production and thrust, tend to remain constant throughout the burn time. In hollow cylindrical grains, plastic inhibitors bonded to the grain limit burning area during the first part of the burn period. Cylindrical grains have holes at regular intervals to equalize pressures inside and surrounding the cylinder.

Like gun propelling charges, rockets must be stowed under conditions favorable to storage. Normally, rocket motors are stowed in different magazines from the heads with which they are used. Like pyro powder, double-base propellants

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such as ballistite must be protected from excessive heat and from moisture. Rocket motor magazines are ventilated, cooled, and inspected daily just like smokeless powder magazines. Rocket propellants are not subjected to surveillance or oven tests aboard ship. A shelf-life date is stencilled on the motor, if required. If the motors have short-circuiting tabs on the leads to the firing squib, these must be left on the rocket until the rocket is to be fired.

On many rocket motor tubes is printed the critical temperature above which the rocket should not be fired. Nor should a rocket motor be used if parts are missing, if the propellant grain is fractured, or if it is loose in the motor tube.

4B7. HIGH EXPLOSIVES

A high explosive for military use must ideally have the following qualities:

1. Low sensitivity to shock of handling, gunfire, and impact against armor.
2. Maximum power.
3. Good fragmentation characteristics (i.e., ability to break up its container into lethal fragments upon detonation).
4. Low cost for manufacture, handling, and loading.
5. Maximum stability for good durability and resistance to adverse conditions like moisture, heat, etc.

No single explosive meets all these requirements suitably for all applications, so the Navy uses a number of explosives. The important ones which will be studied here are TNT, RDX, HBX, tetryl, and Explosive D. Explosives used only for demolitions will not be discussed. Of the five explosives named, the first four often are used in varying forms or with other substances intermixed.

TNT (trinitrotoluene), the best known of military explosives, is made by treating the organic compound toluene with nitric acid. At temperatures below about 170° F, TNT is a crystalline substance (white when pure, but yellow to brown as found in munitions), chemically quite stable (it won't react with metals or become unstable even in temperatures approaching 150° F.), and quite insensitive to shock. However, excess moisture makes it hard to detonate; it should be kept dry. It is loaded by casting—pouring the molten substance into a cavity in the projectile or explosive device. Its detonation rate is about 7,000 meters per second. After prolonged storage, cast TNT may give off an oily exudate that is not itself oversensitive but combines with cellulose material such as wood or natural fabric to make an easily combustible and sometimes even explosive compound. This exudate on the exterior of a projectile or other explosive device is a real fire or explosive hazard. It must be wiped off promptly (but without using soap or other alkaline compounds, and without using steel scrapers).

Cast TNT can be used as a bursting charge in gun projectiles (other than armor-piercing), torpedo, rocket, and missile war heads, depth charges, and mines. In granulated form it is more sensitive and can be used as an auxiliary explosive (booster). TNT is also the main component of two other explosives—amatol and tritonal. Amatol, used mostly in very large aircraft bombs, is a mixture of TNT with ammonium nitrate—the mixture is cheaper than straight TNT. Tritonal is a mixture of TNT and aluminum powder. Though the aluminum does not significantly affect the power of the explosive, it increases brisance.

RDX, also known as "Cyclonite" and "Hexogen," is made by nitration of a complex organic compound, and is substantially more powerful and more sensitive than TNT or Explosive D (which is described below). When pure, coating RDX crystals with wax makes it insensitive enough to handle, but its pure crystalline form is nonetheless too sensitive for use as a military explosive. To make it usable, other materials must be added. RDX is available in the following forms:

1. Composition A. A mixture of RDX and 9 percent wax. Since this composition is as insensitive as Explosive D but is more powerful, it is used as a projectile filler in place of Explosive D.
2. Composition B. A mixture of about 60 percent RDX, 40 percent TNT, and less than 1 percent wax. It is used as a projectile and bomb filler.
3. Composition C. A plastic mixture of about 90 percent RDX and 10 percent emulsifying oil, used as a demolition explosive.

HBX. There are in service use two varieties of HBX: HBX-1 and HBX-3. HBX-1 is a cast explosive, consisting of a mixture of RDX, TNT, aluminum powder, and a desensitizer (chiefly wax). Stable, relatively insensitive to impact, and more powerful than TNT, it is used as a rocket head burster. HBX-3 has a much

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larger proportion of aluminum powder to increase brisance, and produce much greater destructive effect underwater. It is used in depth charges and other underwater explosive devices.

Tetryl is produced by nitration of an aniline-based organic compound, and is both more powerful and more shock-sensitive than TNT. It is used as a burster in small gun projectiles (40-mm and 3"), but is more generally employed as an auxiliary or, when mixed with a primary explosive, in detonators.

Explosive D. This noncommittal appellation continues to reflect the aura of secrecy that once surrounded this explosive, in the closing years of the last century. What made it the subject of cloak-and-dagger concealment was its then revolutionary combination of high power (nearly that of TNT) with sensitivity so low that an armor-piercing projectile containing an Explosive D burster can be fired through armor plate without being detonated. It is a phenolic compound in crystalline powder form, chemically stable up to 150° F. when not exposed to unprotected metal. (Burster cavities in armor-piercing projectiles are protected by varnish before Explosive D is loaded.)

4B8. PRIMARY (INITIATING) EXPLOSIVES

The first chemical reaction in the train or series of stages which culminates in the detonation of an explosive burster or the burning of a propellant occurs in the primary explosive. The primary explosive is the most sensitive in the train, and is present in the smallest quantity. (Detonation of a "blockbuster" bomb with thousands of pounds of high explosive burster begins with the miniature explosion of a few grams of initiator.) The primary explosive may be set off by the impact of a small firing pin, by the heat produced by the passage of a firing current through a platinum filament, or by some other appropriate stimulus. To ignite a propellant, the primary element in the train (the primer) must produce a hot flame of sufficient temperature, size, and duration for reliable action. To detonate a high explosive, the primary element in the train (the detonator) must produce a shock sufficient to detonate the succeeding elements. The primary explosives most often used in naval ammunition today are lead azide, lead styphnate, DDNP, tetracene, and nitromannite. (Mercury fulminate, once the leading primary explosive, has not been superseded because of its disadvantages.)

Detonators and primers differ chiefly in auxiliary ingredients. Thus, oxidizing agents such as nitrates or chlorates are added to increase shock effect and sensitivity; abrasives like ground or powdered glass increase sensitivity to firing pin action; fuels such as antimony trisulfide increase flame energy. Explosive binders like nitrocellulose or nitrostarch are used to provide structure for the primary mixture and to hold it in place, and graphite or other electrical conductors are used to increase conductivity for electrical initiation.

4B9. AUXILIARY EXPLOSIVES

Auxiliary explosives are the middlemen of the explosive or propellent train. They function as "amplifiers" to transmit the relatively feeble explosive shock or the intense but ephemeral flame produced by the primary element, increase it, and get the main charge of insensitive explosive to detonate or the propellant to start burning.

In explosive trains, the auxiliary explosive element is generally called a booster. For detonating large masses of bursting charge (as in some aircraft bombs and mines), more than one booster may be used. Auxiliary explosives widely used in munitions include purified granulated TNT (which is more sensitive than cast TNT), tetryl, and black powder.

Black powder is the principal auxiliary explosive in propellant trains. It is the oldest of explosives; its use in guns dates back to the 12th century. It is a mechanical mixture (not a compound) consisting mainly of saltpeter (sodium nitrate) with lesser proportions of charcoal and sulfur. The exact ratios of the components vary, depending on the application. It comes in varying grain sizes, which are used as indicated:

1. Large grains.—Torpedo and depth-charge impulse charges.
2. Granular.—Ignition charges for propellants and for saluting charges.
3. Fine-grain.—Primer charges; expelling charge in illuminating projectiles.
4. Meal.—Pyrotechnics and fuzes.

Except for application No. 1 above (which, as later chapters in this course will mention, is rapidly becoming obsolete), black powder is no longer used as a propellant. When it was so used in guns, it fouled the bore with unburned residue, made large quantities of irritating and easily visible black smoke, produced a brilliant flash when fired, caused excessive erosion, and even

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with scientifically shaped grains to retard burning rate, it burned much too fast for efficient use of the energy developed.

Black powder is, with justice, considered the most dangerous explosive handled aboard a man-of-war. Although it possesses practically unlimited chemical stability if stored in airtight containers, it deteriorates irregularly when exposed to moisture, which it absorbs readily. Black powder is not affected by moderately high temperatures, nor is it subject to spontaneous combustion at ordinary storage temperatures. It is, however, highly combustible, very sensitive to friction, shock, sparks, or flame, and extremely quick and violent in its action when ignited. Black-powder dust is exceedingly dangerous, and its accumulation during the handling of any black powder should be prevented.

4B10. PYROTECHNICS

Pyrotechnics is based on the Greek for fireworks. The Navy uses pyrotechnics not for celebration but for illumination, signaling, and marking. A pyrotechnic charge is a mixture of chemicals (generally oxidizing agents and combustibles) which reacts to produce light or smoke. Other chemicals may be added to the mixture to color the light or smoke. Some pyrotechnic devices have small quantities of explosive or propellent materials to project the pyrotechnic components in a desired direction, or to scatter them.

The Navy utilizes a large variety of pyrotechnics, but only a few common examples, all used on surface vessels, can be taken up here.

Illumination device. The illuminating projectile (colloquially called a "star shell") is a bright-burning flare that is conveyed to the desired location by firing it in a projectile body from a gun. A timing device causes the flare to be ejected from the projectile and ignited. It falls slowly, supported by a parachute. The illuminating projectile is the only pyrotechnic fired from a gun. The light of its flare is intended to illuminate the target and make it easier to aim other guns.

SIGNALING DEVICES. Three important pyrotechnic signaling devices are signal lights, Navy lights, and distress signals. Signal lights (often called by their older name of Very lights, but not because they are very light) look like shotgun cartridges, and are fired from a special small projector or a special pistol to a height of about 200 feet, at which time a red, white, or green "star" or small flare ignites and burns for 5 to 7 seconds. The Navy light is a hand-held flare, either blue or red, which burns steadily for 1 to 3 minutes. The distress signal is a hand-held double-ended affair which functions, like the famious pyre in Exodus, to produce smoke (orange colored) by day (from one end) or a bright light by night (from the other end).

MARKING DEVICES. A common marking device is the depth charge marker, of which there are two types. When a depth charge pattern is dropped, a marker is also thrown overboard to indicate the location of the pattern. (Details on depth charges and how they are used appear later in this book.) The marker for daytime use has a small black powder charge that scatters bright yellow dye in the water; the night marker has an acetylene lamp that automatically ignites in the water.

4B11. CHEMICAL AGENTS

Chemical agents are of five main types, as described below. They may be used in any of several types of ammunition (depending on the target and the effects desired), or may be released as free liquids or gases from projectors or sprayers. The types are:

Group A. Persistent vesicants. Vesicants blister the skin. The usual ones are mustard gas and lewisite. (Physically, both of these are liquids, not gases.)

Group A-1. Nonpersistent lethal gases. These gases, such as phosgene, injure the body when applied externally, breathed, or taken internally.

Group B. Lacrimators and smokes. A lacrimator such as CH causes weeping and irritation of the throat and lungs. Smokes such as FM and FS are used for screening but have an irritant and, in enclosed spaces, a toxic effect.

Group C. Spontaneously inflammable agents which can be used as incendiaries, such as WP (white phosphorus).

Group D. Readily inflammable mixtures such as TH (thermite), or napalm, a syrupy gasoline-plastic mixture, both of which burn rapidly and with extreme heat and are used as incendiaries.

Chemical warfare is a specialized field which calls for considerable special training. The storage of chemicals requires extraordinary safety precautions. Although poisonous gases were not used in World War II, the Navy was prepared for defense and for reprisal in case

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the enemy initiated such tactics. Chemical warfare creates many problems in ship protection and decontamination which are the responsibility of the Damage control officer and are outside the scope of this book.

4B12. DEMOLITION

Explosives intended for such uses as blasting, eliminating hazards to navigation and obstacles to amphibious landing, and destroying gear to prevent capture by the enemy, comprise demolition material.

Demolition techniques are taught in special Navy schools and will not be discussed in detail in this text. For major blasting operations, various forms of dynamite are used; but dynamite normally is not carried aboard ship.

Half-pound demolition charge blocks, consisting of either pressed TNT or cast TNT and tetryl, are issued to ships for general use. Large demolition charges, also consisting of TNT, and assembled with half-pound booster charges, are also issued for major projects, such as scuttling vessels. Charges of both of these types are detonated by means of blasting caps, set off by electric current.

Highly classified instruments must be completely destroyed if capture or abandon ship is imminent. They are therefore equipped with tiny bombs called destructors, which can be actuated at a moment's notice. Usually, they contain lead azide or TNT-tetryl, with appropriate electric ignition elements.

C. Ammunition

4C1. GENERAL INTRODUCTION AND DEFINITIONS

In a general sense, ammunition includes anything that is intended to be thrown at the enemy or put in his path, to deter, injure, or kill his personnel, or to destroy or damage his materials. In this book, the term is used in a much narrower and more technical sense. Ammunition includes any projectile or explosive weapon, as well as components or parts thereof, but not guns or weapon launchers and their parts.

The section following this introductory article is devoted chiefly to gun ammunition. Other types of ammunition to be taken up later in this book include mines, torpedoes, antisubmarine weapons, bombs, rockets, and grenades. Chemical agents, pyrotechnics, and demolition materials, all of which are also considered ammunition, were taken up in the preceding section. This book, as mentioned in chapter 1, does not cover two other types of ammunition—nuclear weapons and guided missiles.

Service ammunition is ammunition fit for service use and including all explosive and propellent components. Inert (i.e., lacking explosive and propellent componerts) and partially inert ammunition of several types is used for test, training, and practice purposes. Dummy or drill ammunition (completely inert) which resembles service ammunition in appearance, size, and weight, may include functioning components that contain no explosive or propellant. It is used for training and test purposes. Cutaway ammunition (completely inert) has a section cut away to show inner construction and components; it is used for training and display purposes. Plaster-loaded or sand-loaded ammunition lacks the explosive burster charge, but is otherwise not inert; it is used for target practice and for testing of launchers, mounts, or projectors.

A few miscellaneous types of ammunition deserve brief mention for the sake of completeness. An impulse charge (generally of black powder) is a propelling charge designed to project a torpedo or depth charge a short distance. (Impulse charges are becoming less and less commonly used as old-type above-water torpedo tubes and conventional depth charges obsolesce; they are rarities already.) Trench-warfare ammunition includes hand and rifle grenades, mortar projectiles, and similar infantry weapons (issued to Marines and landing forces) for ground combat. Blank ammunition is a type of gun ammunition with propelling charge but no projectile, used for saluting, signaling, and training.

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4C2. TYPES AND COMPONENTS OF GUN AMMUNITION

Components of gun ammunition are called ammunition details, and all the ammunition details required to fire one shot are said to comprise a complete round. Ammunition details include propelling charges, projectiles, primers, boosters, cartridge cases, etc.

Gun ammunition comprises four types: bag, semifixed, fixed, and small arms (fig. 4C1). The distinction between the first three depends on the manner in which the charge is assembled. In bag (formerly called separate-loading) ammunition, the primer, propelling charge, and projectile are separate units. In semifixed ammunition, the primer and propelling charge are contained in one unit, while the projectile is separate, so that the complete round comprises two pieces. In fixed ammunition, all three components are assembled in one unit. Small-arms ammunition, used in small-arms weapons, will not be discussed in this text.

The principal components of gun ammunition are propelling charges and projectiles. The propelling charge functions to develop thrust that ejects the projectile at the proper initial velocity or I.V. (defined as the velocity, generally measured in feet per second or Fps, at which the projectile is moving at the instant it leaves the muzzle of the gun). The projectile generally contains explosive, or it may contain an inert filler or no filler. The propelling charge as an assembly is considered to include the propellent train as well as the propellent itself with its container. The projectile as an assembly includes the fuze, the burster, and the explosive train, as well as the projectile body.

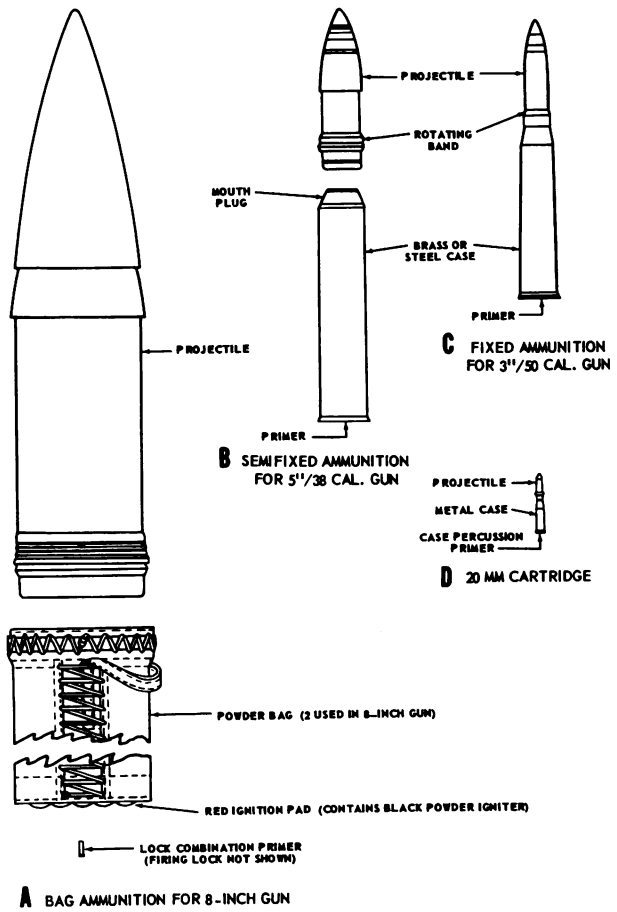

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Figure 4C1.—Complete rounds of gun ammunition. A. Bag. B. Semifixed. C, D. Fixed.

4C3. BAG AMMUNITION PROPELLING CHARGES

A complete round of bag ammunition (fig. 4C1, part A) consists of three different kinds of separate ammunition details:

1. A lock combination primer (so called because it fits into a firing mechanism called a firing lock, and has a combination arrangement which enables it to fire either on an electric firing impulse or by percussion).
2. Two or more powder bags.
3. A projectile.

Large guns must burn large quantities of propellent powder to develop the projectile I.V. required. In a gun as large as 16-inch, several hundred pounds of propellant are needed for one full service round. By dividing this into several fabric bags, each of which can be handled by one man, the gun can be loaded in relatively brief time. Each bag is made of silk (because silk will burn without leaving a smoldering ash), has silk straps for handling and silk lacing to cinch it up, and in red-dyed quilted silk pockets at one end has coarse black powder to serve as the igniter in the propellent train. The bags are kept in airtight steel tanks until just before firing.

Even as late as the beginning of World War II, many naval guns 5-inch and 6-inch in caliber used bag propelling charges. With the increased mechanization of ammunition handling, to which

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propelling charges in bags are not well suited, the use of bag ammunition has declined until it is now used in the active fleet only in 8-inch main-battery turret weapons in Baltimore and Boston class cruisers. There are larger bag guns in the reserve fleet (CBs have 12-inch bag guns, and BBs have 16-inch bag guns), but not at present in active service.

A complete loaded round of bag ammunition is shown in a cross-sectioned gun in figure 4C2. The primer, a small cylindrical metal container with one end open and the opposite end closed and rimmed, is loaded manually into a firing lock in the breech plug. The projectile is pushed into the gun by a power-driven manually controlled rammer. Next, the gun crew rolls the propelling charge into position for the rammer to push it into the gun behind the projectile. The last step in loading is for the gun crew to close the breech manually by swinging the breech plug into place and locking it. The gun can now be fired. This is done either by passing a small electric firing current through the primer, or manually operating a mechanical percussion device on the firing lock (not illustrated). The primer produces a spit of flame which travels through a bore or vent in a mushroom-shaped spindle in the breech mechanism and sets fire to the igniter in the after end of the rearmost bag. This sets off the remainder of the charge. After the projectile has left the muzzle, the breech can be opened, and an air blast from a gas ejector clears the gun bore of residual gases. After inspection to verify that there is no burning residue in the bore, the next round can be loaded.

4C4. CASE TYPE PROPELLING CHARGES

Gun ammunition which has its propellent charge in a metal case or cartridge instead of a bag is called case ammunition. (The term "cartridge" may also be applied to a complete round of small-arms ammunition.) Both semifixed and fixed ammunitions are of this type. The primer in all case ammunition is inserted in the base of the case at the ammunition depot and is not removed or changed aboard ship.

The designs of various sizes of case ammunition are similar, as may be seen from study of figure 4C3. The case assemblies are similar up to the point at which the mouth is sealed. In fixed ammunition the projectile is the seal; a mouth plug is used in semifixed ammunition.

There are four steps in the assembly of case ammunition: (1) priming, (2) loading the propellant, (3) fitting a wad and sometimes a distance piece, and (4) inserting the projectile or mouth plug. In priming, the primer used is either screwed (40-mm and larger) or force-fitted (smaller cartridge ammunition) into the base of the case. The desired weight of smokeless-powder grains is then dumped loosely into

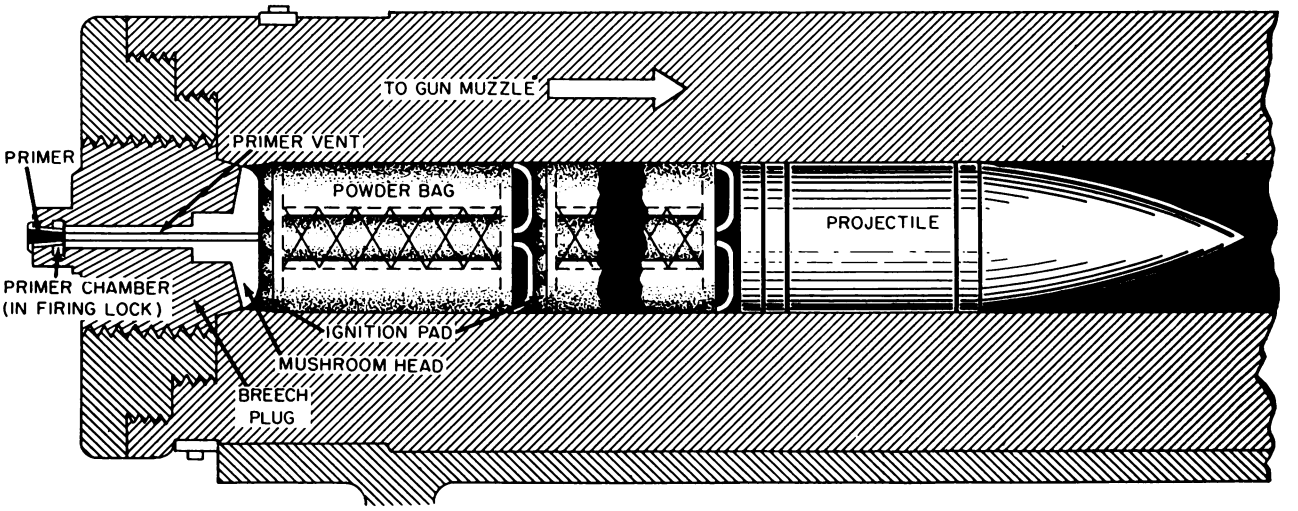

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Figure 4C2.—Complete round of bag ammunition, loaded and ready for firing. Cross section.

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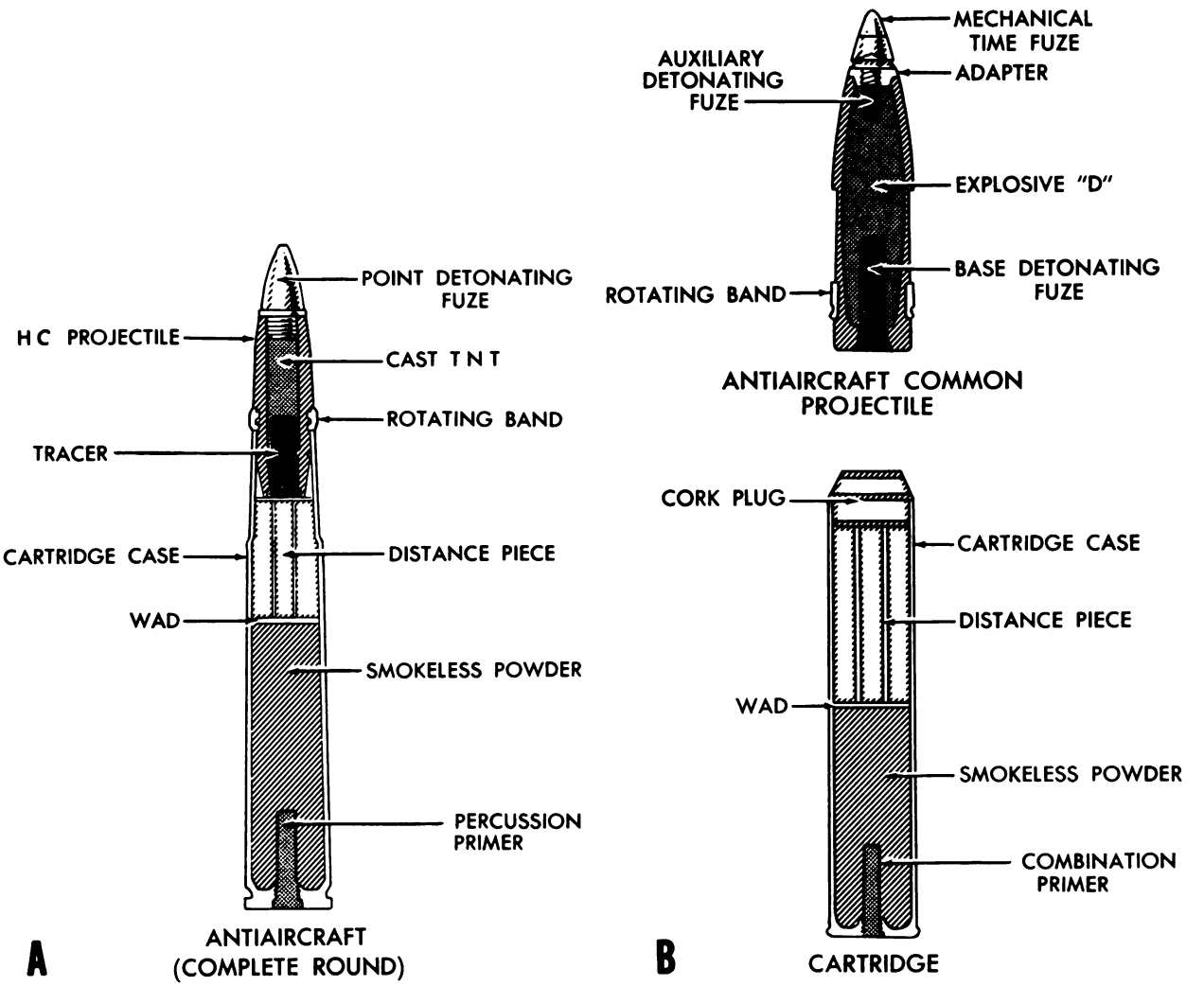

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Figure 4C3.—Case ammunition. Cross sections.
A. Fixed ammunition (40-mm).
B. Semifixed ammunition (5"/38).

the case. In 40-mm and larger guns, a cardboard or wad is forced into the case and a distance piece, if one is needed, placed on top. (This prevents shifting of the powder during handling.) The mouth of a semifixed case is then sealed by a mouth plug. In fixed ammunition, the mouth of the case is sealed by forcing the base of the projectile into the case.

The case is cylindrical but tapers slightly from base to top, and has an annular groove and rim at the base end. Cartridge cases have in the past generally been made of brass (hence the term spent brass to designate used cases aboard ship). Steel cases are now the standard in most calibers. Plastic cases are under development. Regardless of what it's made of, regulations require that spent "brass" must be conserved. After a brief ventilation period (to dispose of residual powder gases), it must be stowed until the ship can return it to an ammunition depot to be reused.

The primer-igniter arrangement in case ammunition is different from that in bag ammunition. The primer is always secured to the

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center of the base of the case. Primers for ammunition of larger caliber than 3" include an igniter charge (black powder); smaller ammunition generally does not require an igniter, although black powder may be present in the initiator mixture.

Figure 4C4 shows the three types of primer. In percussion primers, the impact of a firing pin (in the gun) on a primer cap imparts a blow to a sensitive initiating mixture between the cap and a metal anvil. This initiates an explosive reaction whose flame ignites the remainder of

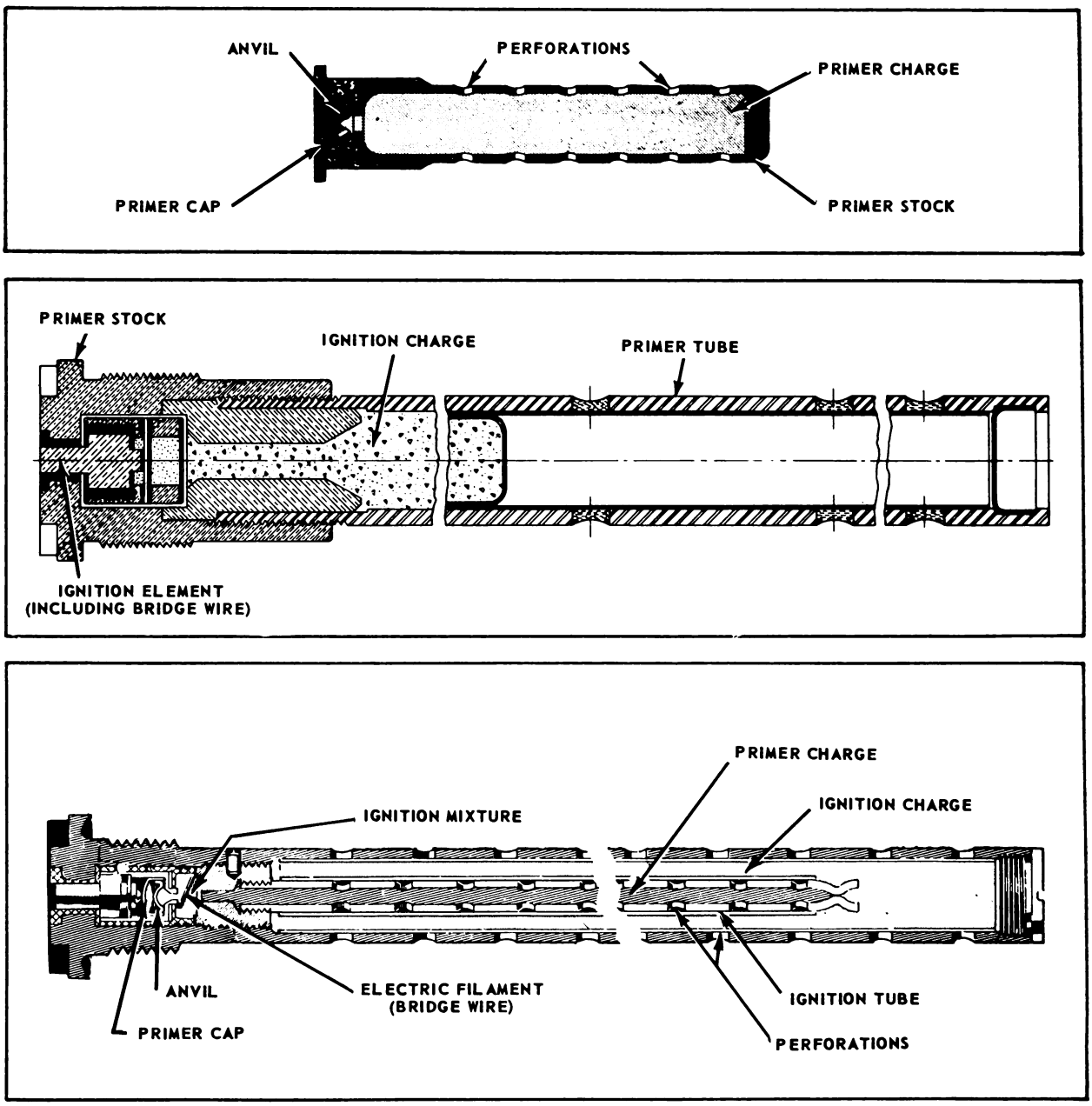

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Figure 4C4.—Case primers. A. Percussion primer. B. Electric primer. C. Combination primer.

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the primer charge. In electric primers, a brief pulse of firing current heats a small bridge wire which ignites the initiating mixture; the flame thus produced is transmitted to the ignition charge, which in turn sets off the propelling charge. The combination primer has both a bridge wire and the cap-anvil arrangement; either can start the reaction. Electric firing is preferred with combination primer ammunition.

4C5. PROJECTILES

The projectile is the part of a complete round of service gun ammunition that is expelled at high velocity from the gun bore by the burning of the propelling charge. Modern projectiles are cylinders with pointed noses. Such a projectile can give stable ballistic performance only if it spins about its long axis while in flight—otherwise it will tumble erratically. As will be explained later in further detail, the bores of modern guns are spirally grooved (rifled) so that the projectile will develop this spin as it travels along the bore.

Modern small-arms and machine gun projectiles often consist of solid metal; projectiles used in larger guns, however, are assemblies of several components. The three essential parts are the metallic body, the explosive bursting charge, and the fuze which sets off that charge. There may also be a tracer to make the projectile more readily visible during flight.

The solid bullet damages by impact alone. Assembled projectiles, however, inflict damage primarily by the blast of the high-explosive charge and resulting high-velocity fragments.

EXTERNAL FEATURES OF PROJECTILES. The external shape of the projectile is designed to obtain the desired flight characteristics of stability and minimum air resistance. The form of forward end which best fulfills these conditions is the ogival curve (generated by revolving an arc of a circle about a chord). In a projectile the chord is the axis of the projectile and the radius used is about nine times the diameter (caliber) of the projectile. In small-caliber projectiles a cone is sometimes used instead, but this part of the projectile is still called the ogive. Abaft the ogive the projectile is cylindrical. The cylindrical shape may continue to the base (making a square base); or the after portion may be slightly tapered, (making it boat-tailed). Near the after end of the projectile is the rotating band; forward of this is the bourrelet (fig. 4C5). These two surfaces, slightly larger in diameter than the body, support and steady the projectile in its passage through the gun.

In small projectiles the entire body forward of the rotating band may be finished to bourrelet diameter. On large-caliber projectiles additional bourrelets, forward of the rotating band, are added to provide better support. The bourrelet is very slightly smaller (0.015 to 0.030 inch) than bore diameter.

The rotating band, on the other hand, is actually larger than bore diameter. Its three main functions are (1) to seal the bore, (2) to position and center the rear end of the projectile, and (3) to engage the helical rifling grooves in the gun bore so as to impart rotation to the projectile. It also holds the projectile in position in the gun after loading and ramming so that it will not slip back when the gun is elevated.

Rotating bands are generally made of copper, either pure or alloyed. (Experiments have been made with rotating bands of sintered metal; these have not been adopted for service at present.)

PROJECTILE MARKINGS. To facilitate rapid identification by personnel who handle them, projectiles are painted with distinctive colors and code patterns to show type, loading, etc. Certain parts must not be painted; others must have no more than one coat. Specific marking details may be found in OP223B, Identification of Ammunition, and in MIL-STD 709, Military Standard Ammunition Color Coding.

PROJECTILE WEIGHT. Within limits a gun can fire projectiles of different weights. The weight of U. S. Navy projectiles is determined by the formula

$$W = \frac{d^3}{2}$$

in which: W = weight of projectile in pounds, and

d = caliber of gun in inches.

The weight of the projectile per square inch of bore is called sectional density. It is represented by the expression

$$SD = \frac{W}{A}$$

in which: SD = section density.
W = weight of projectile in pounds.
A = area of bore, including grooves in square inches.

This ratio varies with the size of the gun, averaging approximately six-tenths of the caliber.

The distribution of weight in a projectile is a matter of considerable importance. The center of gravity should be in the longitudinal axis and close to or abaft the center of form.

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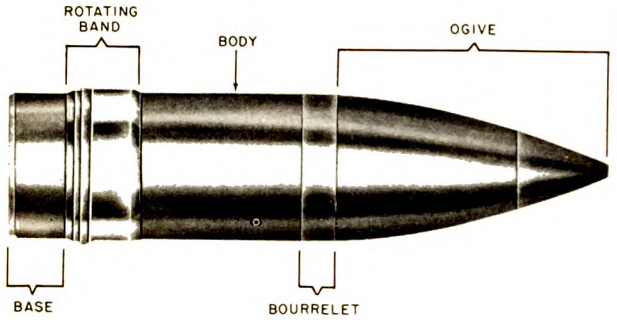

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Figure 4C5.—External features of gun projectile.

CLASSIFICATION OF PROJECTILES. All gun projectiles, other than small arms, share the characteristics so far described. Since targets differ in character, projectiles must differ in design to defeat them most effectively. There are three general classes of projectiles:

1. Penetrating.
2. Fragmenting.
3. Special purpose.

In each class are one or more types, each designated by a specific letter code.

Penetrating projectiles. Penetrating projectiles include armor-piercing (AP) and common (COM). They are designed to penetrate, respectively, heavy and light armor. The usual bursting charge for these types is Explosive D, which is insensitive enough to permit penetration without premature detonation.

Figure 4C6 shows the construction of a typical AP projectile. The body has thick walls, a relatively small burster charge cavity, a nose cap, and a thin metal windshield. To function effectively, an armor-piercing projectile must keep its burster charge intact until it has penetrated its target. The projectile body, of tough steel, backs up the hardened but somewhat brittle steel nose cap, which is so shaped that it will dig into and cut through an armor-plated target, rather than ricochet. However, in flight the blunt nose cap, which is shaped for penetration of armor, not for streamlining, would give the projectile the ballistics of a brick. Hence the windshield, which collapses upon impact with the target, is screwed on to give the exterior of the projectile a satisfactory ogival shape. AP projectiles in larger calibers are not efficient against lightly armored targets, because of their small bursters. The projectile is delay-fuzed to burst after penetration.

The common projectile, illustrated in figure 4C7, has a hood instead of the armor-piercing cap, a larger burster, and thinner walls, and is suited for more lightly armored targets than AP projectiles.

Fragmenting projectiles. Fragmenting projectiles are designed to damage by both blast effect and fragmentation—that is, breaking up into high-velocity fragments. Such projectiles characteristically have relatively thin walls and large cavities for the burster. Under this general classification are the following types:

1. High-capacity (HC). A typical HC projectile is illustrated in figure 4C8. This type is used against unarmored surface targets, shore objectives, or personnel. Since no penetration ability is required, explosives more sensitive than Explosive D may be used.

2. Antiaircraft (AA) projectiles are designed for use against airplanes in flight. Except for fuzing they are substantially the same as HC in the larger calibers. In smaller sizes the explosive often contains an incendiary element.

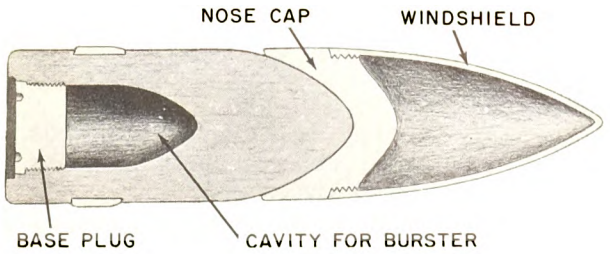

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Figure 4C6.—3-inch armor-piercing projectile. Cross section.

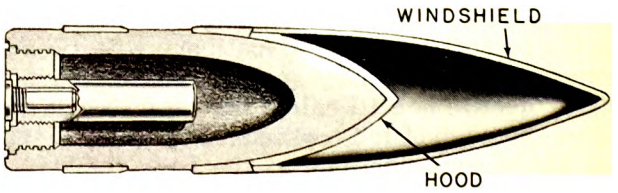

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Figure 4C7.—3-inch common projectile. Cross section.

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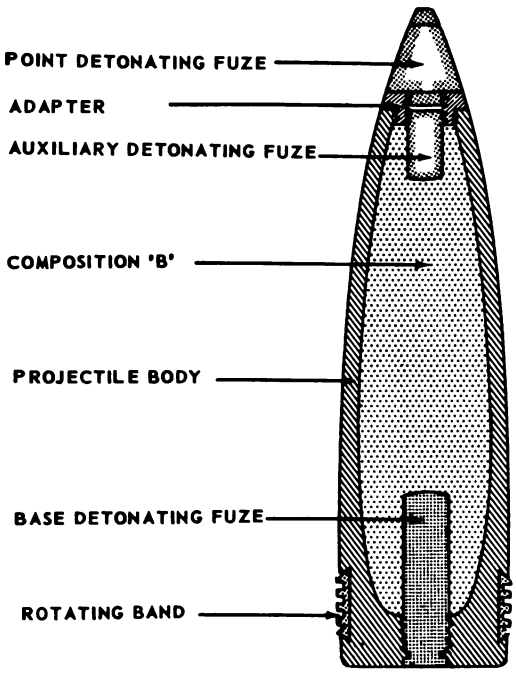

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Figure 4C8.—6-inch high-capacity projectile.

3. Antiaircraft common (AAC) projectiles are a dual purpose design, combining the qualities of antiaircraft projectiles with the toughness necessary to penetrate steel plating not of armor thickness. The type of fuzing will depend on the use. The walls may be heavier than those of the other thin-walled types, and the filler is usually Explosive D.

Special purpose projectiles. The special purpose classification includes types not intended to inflict damage by blast or fragmentation. If the filler includes any explosive, it is a small charge designed to expel the contents of the projectile. See figure 4C9. The common varieties are:

1. Illuminating (ILLUM) projectiles, often called star shells (SS), contain a bright flare attached to a parachute; these are expelled from the projectile by a small black-powder charge which also lights the flare. As the parachute slowly lowers the flare, it illuminates the target.

2. Smoke projectiles contains tubes of white phosphorus (WP) which are scattered and burst by a small black-powder charge. White phosphorus produces a screening smoke, and has an incendiary effect.

3. Window (W) projectiles contain metal foil strips, which are scattered high in the air by a small burster charge to confuse enemy radar.

4. Nonfragmenting ("nonfrag") projectiles are used for antiaircraft gun practice. They contain a smoke-producing substance, available in various colors, to make observable bursts without destroying the target by fragmentation.

5. Target or blind-loaded (BL) projectiles contain sand or other inert substance to give the same weight and balance characteristics as explosive fillers.

4C6. FUZES

A projectile fuze is a mechanical or electronic device which will detonate or ignite a charge in a projectile at the time and under the circumstances desired.

Fuzes may be classified according to function (impact, time, auxiliary, or proximity), the position of the fuze in the projectile (nose or base), type of mechanism or principle utilized (mechanical or VT), and specific action at time of functioning or initiation (ignition or detonation). Figure 4C10 illustrates locations of typical fuzes.

Typical examples of nomenclature for Navy fuzes are as follows:

1. Auxiliary detonating (ADF).
2. Base detonating (BDF).
3. Mechanical time (MTF).
4. Point detonating (PDF).
5. VT or proximity (VTF).

Point detonating, time, and VT fuzes may all be called nose fuzes because of their location in the projectile. Fuzes are designated as detonating when they contain within themselves a high-explosive charge sufficient to set off a high-order explosion in the burster. Ignition fuzes contain black powder sufficient to ignite the burster of small projectiles. In larger projectiles such fuzes function indirectly through an auxiliary detonating fuze.

For safety reasons a fuze must be inoperative until the projectile is clear of the muzzle and the firing ship. A fuze is said to be armed when it is set to permit initiation of the explosive train. It is unarmed when set to prevent initiation.

A satisfactory fuze must:

1. be safe to handle; that is, the fuze must not arm if dropped or joggled.

2. be safe after firing until it is at a safe distance beyond the gun bore. A fuze with this characteristic is said to be boresafe.

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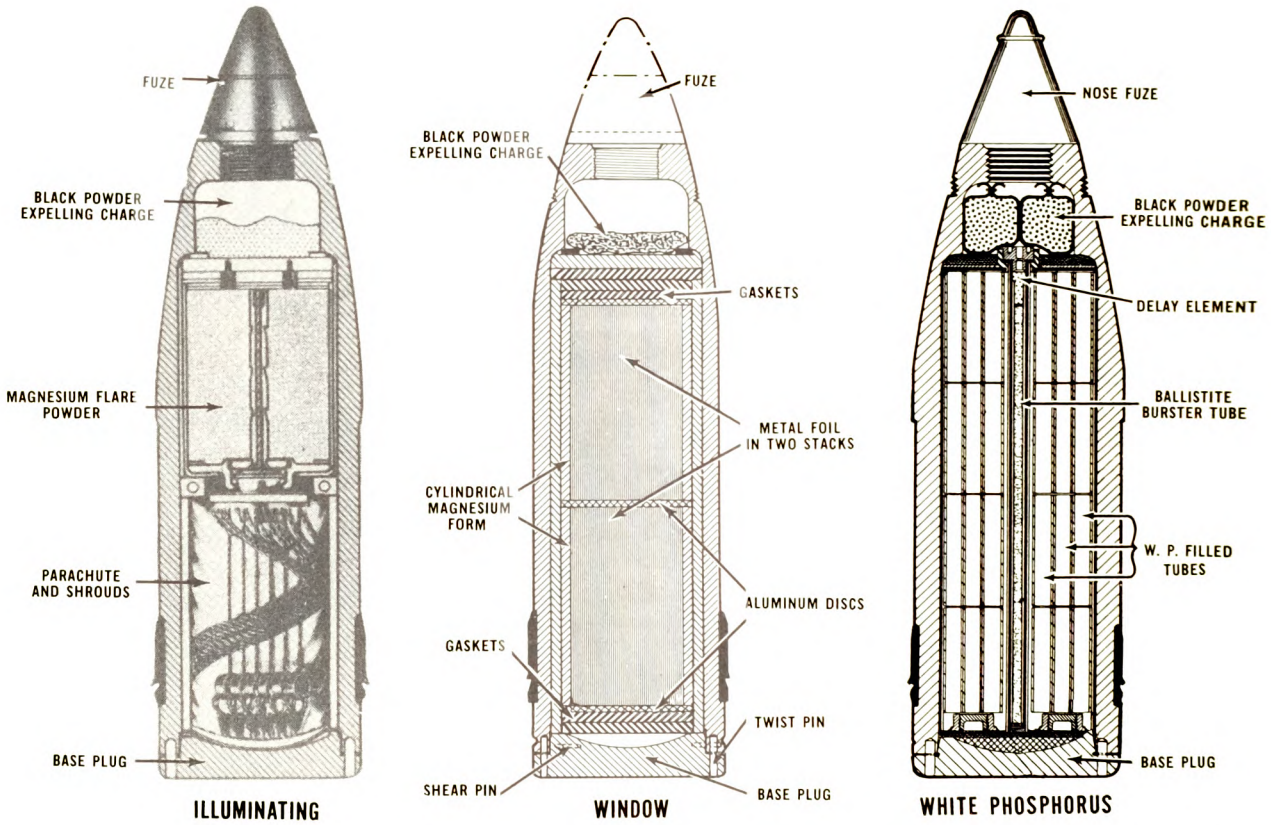

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Figure 4C9.—Special-purpose projectiles.

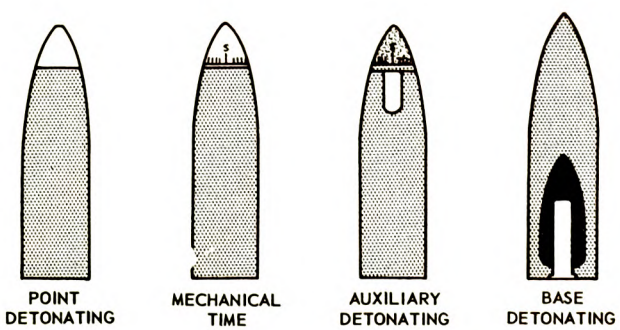

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Figure 4C10.—Fuze locations.

3. function to initiate the explosive train at the proper instant, and not before or too late.

FORCES THAT OPERATE FUZES. From the instant of firing until it strikes its target, a projectile and its components are subjected to a succession of forces (listed below) which can be utilized to start or drive a fuze's mechanism. Many fuzes are complicated and use more than one of these forces, in addition to other energy sources.

1. SETBACK. When the propelling charge is fired, the projectile is (a) accelerated forward and (b) twisted clockwise (as seen from the base). Because of their inertia, movable parts of the projectile consequently develop, during the period of projectile acceleration and twist, a rearward force called setback (fig. 4C11, part A), and a rotational force or torque in the counterclockwise direction (i.e., in the direction opposite to the twist). This torque is called angular setback.

2. CENTRIFUGAL FORCE. In accordance with Newton's laws of motion, any moving particles tends to keep moving in a straight line. Consequently, because of its inertia, a

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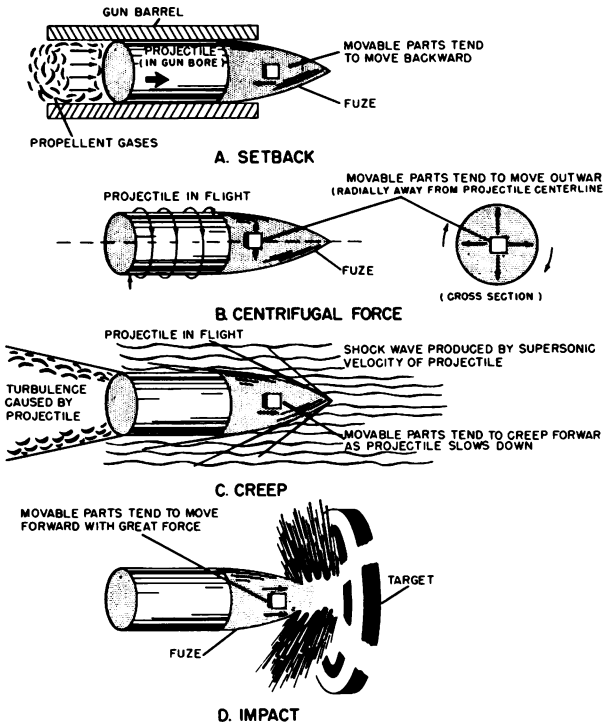

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Figure 4C11.—Forces that work on fuzes.
A. Setback. B. Centrifugal force.
C. Creep. D. Impact.

revolving particle develops a radial thrust (centrifugal force) away from the center of revolution. As shown in figure 4C11, part B, the fuze parts therefore develop a continuous outward thrust from the rotating projectile's centerline while it is in flight.

3. CREEP. The projectile while in flight is gradually slowed by air resistance acting on its exterior surface. Since the parts inside the projectile are not in contact with the air and do not meet this resistance, they tend because of inertia to continue in motion at the same velocity. Thus, as illustrated in figure 4C11, part C, they exert a continuous forward thrust, called creep.

4. IMPACT. When a projectile strikes, its parts because of inertia tend to continue moving forward; this develops considerable force. Impact is generally used to initiate the explosive train (fig. 4C11, part D).

5. TARGET CONTACT (not illustrated). When a firing plunger or other part of a projectile contacts the target, it is driven toward the rear with respect to the remainder of the projectile. Target contact is used to start the explosive train.

TYPES AND APPLICATIONS OF FUZES. Auxiliary detonating fuzes are used in conjunction with all types of nose fuzes in projectiles of 3-inch and greater caliber except illuminating and special purpose projectiles. They prevent detonation if the nose fuze is accidentally actuated before the auxiliary detonating fuze is armed.

Base detonating fuzes are used alone in AP and COM projectiles, and in combination with nose fuzes in such dual purpose projectiles as AAC and HC. In the latter their functioning is completely independent of the nose and auxiliary fuzes. All base detonating fuzes function on impact; some, however, have a delay time (0.02 to 0.033 second) after the projectile hits, to allow time for armor penetration.

Mechanical time fuzes (MTF) are clockwork mechanisms which begin to function upon firing, and initiate the explosive train at a selected time following firing. They are used in high explosive, illuminating, and various special purpose projectiles. When used in high explosive projectiles, these fuzes work in conjunction with auxiliary detonating fuzes. MTFs contain a gear train and an escapement mechanism which starts to operate immediately after the inertia force of setback has ceased. Centrifugal force acting on weights, with or without the aid of coiled springs, supplies the energy to run the clock mechanism. After the predetermined and preset time interval, a spring-loaded firing pin is released and strikes the initial element of the fuze explosive train.

MTFs are used in projectiles with high fragmentation qualities to provide air bursts. Air bursts are effective against personnel if they are timed to burst, say 50 feet above a trench or other occupied area. Gunfire support requirements call for these bursts to be 25 to 50 feet above the target.

Even though they are effective in gunfire support, MTFs are used more often against air targets. Obvious is the superiority of timed projectiles, throwing fragments in all directions, over those which require target contact before detonation. A direct hit is improbable on an air target, but the 5" AAC projectile has been designed to take advantage of this possibility, plus

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the certain advantage of the timed air burst. AACs have a PDF, a BDF, and ADF, and an MTF to make them very versatile projectiles.

Point detonating fuzes (PDF) are designed to function on impact. They are faster acting than BDFs. They are used chiefly against lightly armored targets in gunfire support. PDFs are found in HC, AAC, and WP smoke projectiles. These fuzes are inserted into the projectile's nose in an unarmed condition; they are armed by centrifugal force after the projectile has been fired.

VT are proximity fuzes used in all of the types of projectiles which can use mechanical time fuzes, except illuminating and window. The VT fuze is a self-contained radio transmitter-receiver which receives echoes of its transmission as reflected by a target. When the returning signal is of sufficient strength, as the projectile nears the target, the firing circuit closes. The fuze is rugged and compact; it fits into the nose of a projectile.

VTs are also effective against personnel ashore but are used mainly against air targets. If a VT bursts in the vicinity of an air target, it is considered to be a hit in wartime firing and for peacetime firing practice evaluation. The burst is called a TTB (target-triggered-burst).

D. Guns and Gun Mounts

4D1. INTRODUCTION

The gun has been used in warfare ashore and afloat for several hundred years. Its effectiveness as a weapon has increased over this period, but this development has not been a slow, steady growth. For the first 400 years the technology of gunnery changed so little that a sailor of Elizabethan times would have had to learn very little that was new to have served a gun at Trafalgar (1805). Most of the basic features that have made the modern naval gun the effective weapon it is today were developed in the past 130 years; most of them began to become important only after 1900.

The guns and mounts aboard modern United States naval vessels, complex though they are in detail, are based on a relatively few fundamental features. Once these are grasped, the student will find it easier to master the details of structure and functioning of any gun mount or turret he encounters.

This section is concerned with the fundamental principles of how guns (and gun mounts) are constructed and how they work. Since naval gun mounts are complex, and there is a host of different types, this section makes no attempt to go into detail on any single feature. Instead, the emphasis is on identifying each feature and its purpose, leaving for later study the details of construction and functioning. The section begins with a quick analysis of the fundamental anatomy and nomenclature of the principal parts of a "conventional" gun mount, followed by a brief discussion of each of the significant characteristic features of the modern gun mount.

The gun mount features discussed below are those that are referred to in this book as "conventional," meaning that they represent standard practice in the art of gun and mount design as it exists in the U.S. Navy about the middle of the 20th century. New developments and improvements in guns and mounts are, of course, always in progress.

4D2. COMMON STRUCTURAL ARRANGEMENT OF NAVAL GUN MOUNTS

Figure 4D1 shows the "skeleton" of the structure of a typical 5-inch naval gun mount. In general these parts, their arrangement, and their nomenclature are typical of other naval gun mounts, both larger and smaller.

Serving as the mount foundation is the stand, a steel ring bolted to the deck. The training circle is an internal gear inside the stand.

Supported by the stand, and capable of rotating in train in roller bearings on it, is the base ring, also called the deep section ring or lower carriage. Mounted on it is the upper carriage, a pair of massive brackets braced to hold the trunnion bearings, large roller bearings into which the gun trunnions fit. The trunnions are part of the slide, a rectangular weldment which supports all the elevating parts of the gun. The housing slides in recoil in the slide; the barrel fits into the housing's forward end, and the

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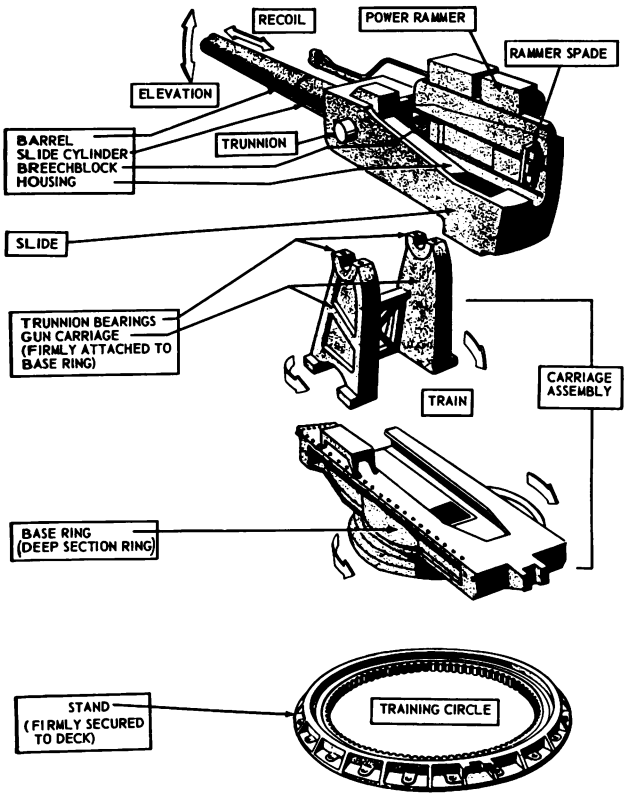

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Figure 4D1.—Main assemblies of a 5-inch mount. Exploded view.

breechblock can slide up and down in a breechway just behind the barrel. Arrows show the movement of which each part (except the breechblock) is capable.

Figure 4D2 shows how the base ring fits into the stand, and how the mount trains. Holding-down clips bolted to the base ring fit under the stand so that the carriage will not tip when the gun fires or when the ship pitches and rolls. The base ring can turn on the stand in two large-diameter roller bearings. One, the roller path, takes up vertical thrust, the other, horizontal. The function of the training circle also is illustrated in figure 4D2. A pinion in the carriage engages the training circle gear teeth to train the mount.

The carriage assembly comprises two parts—the lower carriage (base ring) and upper carriage (fig. 4D3). The base ring supports the upper carriage and platform; the shield (in enclosed mounts) is secured to it. It also supports the mount power drives and other components. In mounts equipped with powder and projectile hoists, the hoists hang from the base ring and train with the mount. The upper carriage supports the trunnion bearings. The trunnion bearings and trunnions, besides supporting the elevating parts, provide connections for air lines (for gas ejection) and mechanical linkages (for percussion firing and for transmission of elevation movement to firing stop mechanisms).

The trunnions are part of the slide (fig. 4D4). The slide is conventionally a rectangular steel weldment which houses or supports all the parts of the gun and mount that move in elevation. In modern mounts designed to engage either air or surface targets, the limits of elevation movement are from minus 10 to 15 degrees (that is, with gun barrel depressed 10 to 15 degrees below the horizontal) to about plus 85 degrees (that is, with the gun barrel within 5 degrees of pointing straight up).

The slide (fig. 4D4) contains the ammunition feed mechanism (or the power rammer if ammunition feed is performed manually with mechanical assistance), the recoil brake, the counterrecoil mechanism, the elevating arc, and the gun housing. Figure 4D4 shows how the elevating arc positions the slide in elevation. The arc, a gear sector secured to the slide, engages a pinion (which may be driven manually or by a power drive) in the carriage.

As you know from the last of Newton's three laws of motion, any action produces an equal and opposite reaction. The thrust which propels the gun projectile out of the barrel is accompanied by an equal and opposite thrust in the opposite direction. This thrust produces a rearward movement, called recoil, of parts of the gun. After the projectile and high-pressure propellent gases have left the barrel, recoil thrust ceases. The recoiling parts of the gun are then forced forward. This forward movement is called counterrecoil, and it continues until the parts that recoiled are restored to their original position before firing. This is called battery position, and the gun is now said to be in battery. Note that in all modern naval guns, only parts of the gun mount recoil; the gun mount as a whole does not recoil with respect to the ship's stjucture.

The recoiling parts of a conventional naval gun are either attached to or housed in the gun housing (or breech housing). See figure 4D5.

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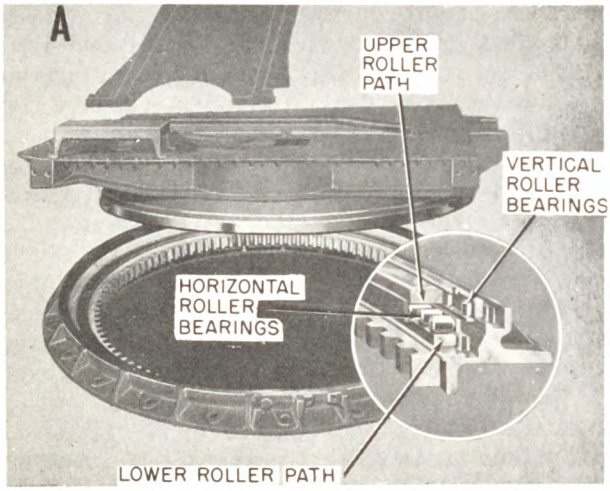

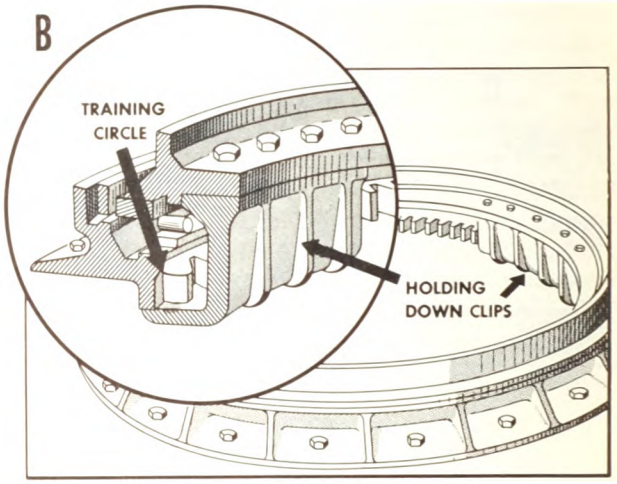

A. Roller bearings.

B. Training circle and holding-down clips.

C. Principle of training gear.

Figure 4D2.—Details of the stand and carriage.

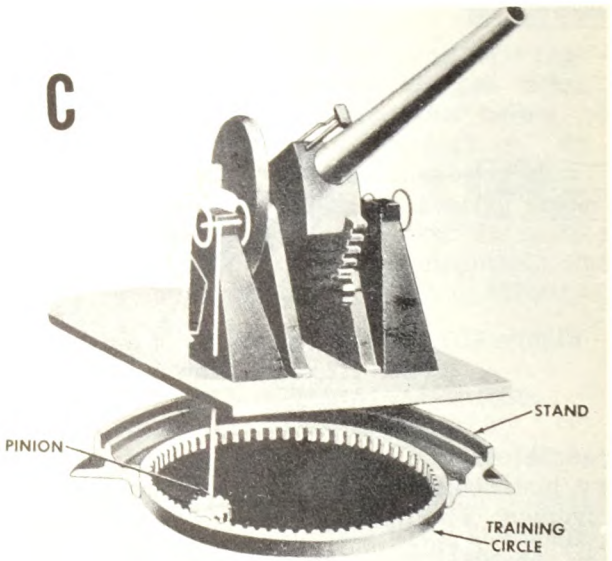

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Figure 4D2.—Details of the stand and carriage. A. Roller bearings. B. Training circle and holding-down clips. C. Principle of training gear.

(Some turret guns and 20-mm guns differ considerably from this type of conventional design; this description is not intended to apply to them.) Secured to the forward end of the housing is the gun barrel itself. The commonest method of attaching gun to housing is by use of an interrupted-screw joint, with a key to lock the barrel against possible rotation. The housing can move parallel to the gun bore axis in ways in the slide. It is normally forced to battery position by a counterrecoil mechanism, to be described later.

When the gun fires, the reaction of the barrel forces the housing aft; this movement is opposed by the counterrecoil mechanism and by a hydraulic recoil brake to be described later.

Figure 4D5 also indicates the location and some features of the breech mechanism. The conventional type, illustrated here, is called the vertical sliding-wedge type.

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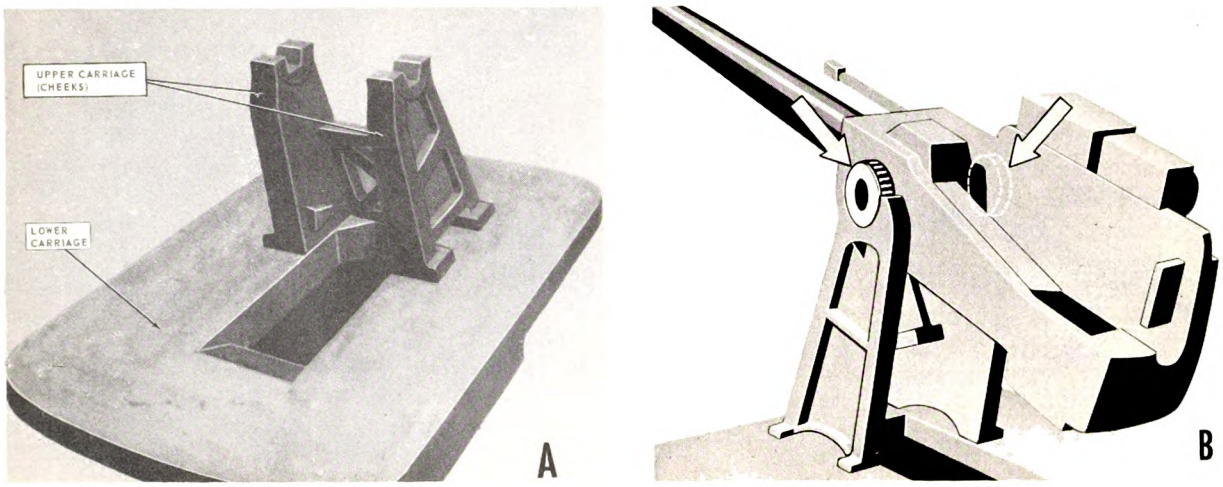

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Figure 4D3.—The carriage. A. Upper and lower carriage. B. Trunnion bearings.

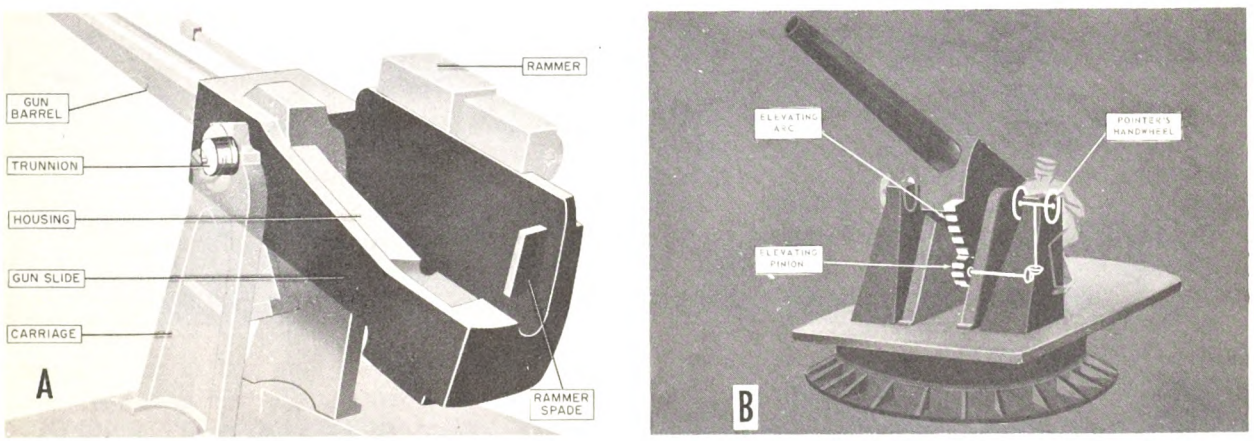

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Figure 4D4.—The slide. A. Main features. B. Principle of elevating mechanism.

4D3. SOME BASIC DEFINITIONS

Study the following brief list of definitions. Some of these amplify or more precisely delimit the terms already taken up in the discussion above of the anatomy of a gun mount, and some introduce terms not yet discussed.

GUN. The term gun properly designates the tube or barrel, but is commonly used to refer to the whole assembly of which the barrel is but a part.

MOUNT. This is the entire system between the gun and the ship's structure. The mount supports the gun, secures the gun to the ship's structure, and provides for its elevation, train, and (in guns larger than 20-mm) recoil and counterrecoil. There are several types of mounts, but all of them must accomplish these functions. Larger mounts have other functions as well.

TRAIN. The train angle of a gun is the position of the axis of the gun's bore in azimuth (or in a plane parallel to the deck), as measured

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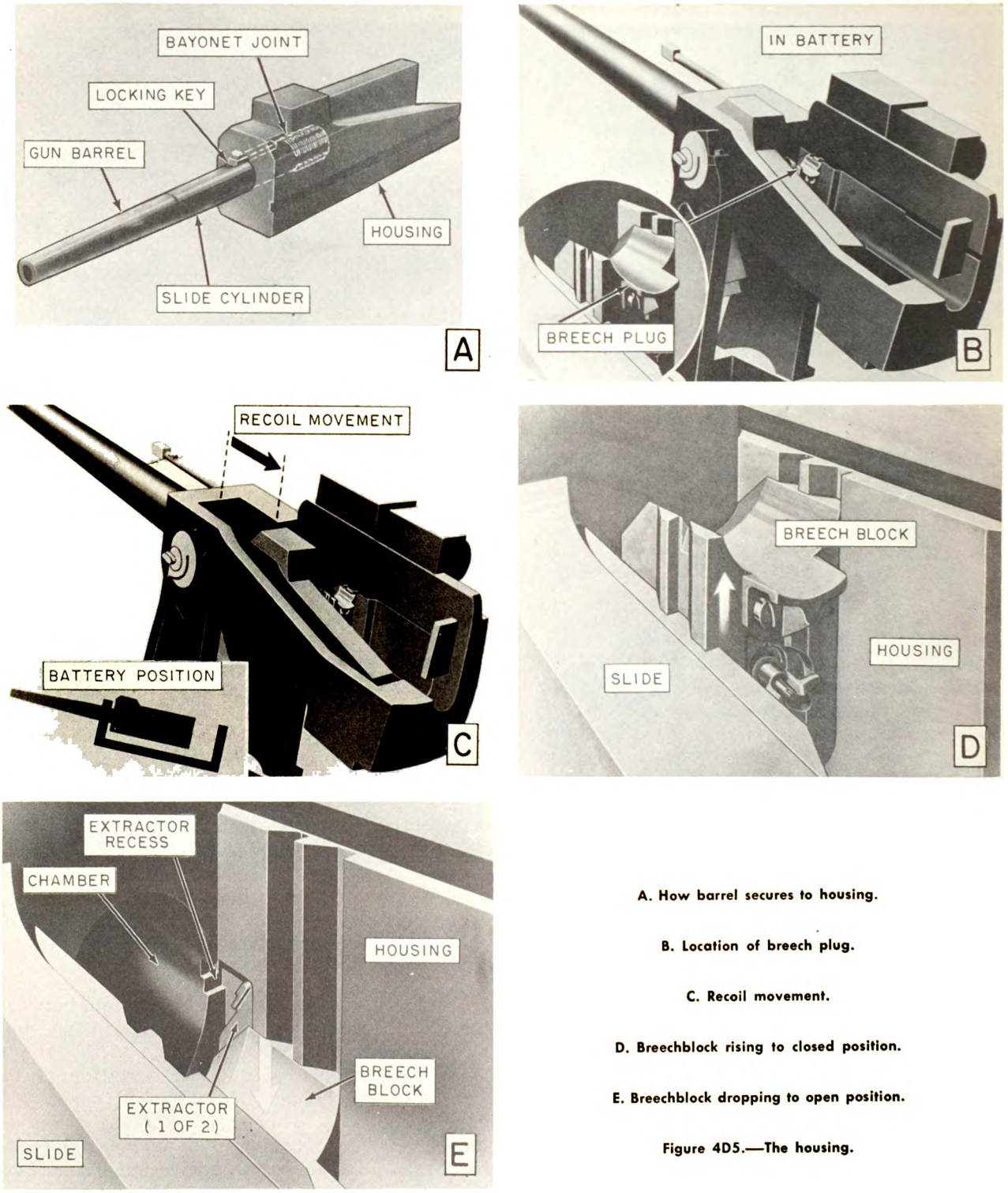

A. How barrel secures to housing.

B. Location of breech plug.

C. Recoil movement.

D. Breechblock rising to closed position.

E. Breechblock dropping to open position.

Figure 4D5.—The housing.

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from the ship's centerline. Training the gun is rotating it in azimuth. The trainer is the gun crew member who controls the training of the gun. The training gear is the equipment used to train the gun.

ELEVATION. The elevation of a gun is the angle that the gun bore axis makes with the deck, measured in a plane perpendicular to the deck. Elevating the gun is increasing this angle; depressing the gun is decreasing this angle. The elevating gear is the equipment used to move the gun in elevation. The term pointing has the same meaning as the terms "elevating" and "depressing" combined. The pointer is the gun crew member who controls the elevation or pointing of the gun.

RECOIL. Recoil is the force tending to push the gun to the rear as the projectile is discharged. It is the gun's reaction to firing. Recoil is also the rearward movement of the gun. The recoil mechanism or recoil brake is the equipment used to control the gun's recoil. Recoiling parts are those that move with the gun in recoil and counterrecoil.

COUNTERRECOIL. Counterrecoil is the forward movement of the gun after recoil which returns the gun to its original firing position. The counterrecoil mechanism (also known as the recuperator) is the equipment that returns the gun to its firing position.

IN BATTERY. A gun in its firing position as regards recoil and counterrecoil is said to be in battery. A gun moves out of battery during recoil and returns to battery during counterrecoil. Recoil position is the rearmost position of the recoiling parts in recoil movement.

HOUSING. The housing of a gun is a generally box-shaped structure joined to the gun barrel with a bayonet-type joint. On most intermediate-caliber guns it houses the breech mechanism. Since it is attached to the gun barrel, it is a recoiling part. Major-caliber bag guns have no housing; these have yokes, which, in general, perform a similar function.

SLIDE. On all guns larger than 20-mm, the slide is the structural part which supports the gun, housing, and other recoiling parts, and permits them to move in recoil.

AUTOMATIC GUNS. Automatic guns are case guns (i.e., guns using case ammunition) in which some of the energy of the propellent explosion is used to open the breech, eject the empty case, and operate a device which automatically loads another round of ammunition. An automatic gun can continue to fire so long as ammunition is supplied and the trigger is operated.

SEMIAUTOMATIC GUNS. Semiautomatic guns are case guns in which some of the energy of the propellent explosion is used to open the breech, eject the empty case, and automatically close the breech when another round is loaded. Semiautomatic guns, unlike automatic guns, must be loaded either by hand or by auxiliary equipment.

NONAUTOMATIC GUNS. Nonautomatic guns are those in which none of the energy of the propellant is used to perform breech opening, closing, or loading functions. All guns using bag ammunition are of this type.

RAPID-FIRE GUNS. Rapid-fire (RF) guns are those in which loading, firing, empty-case ejection, and breech operation are performed automatically but are powered by a source of energy other than the propelling charge.

AXIS OF BORE. The axis of the bore is a straight line passing through the center of the gun bore.

4D4. DESIGNATION OF GUNS BY CALIBER

The caliber of a U.S. naval gun (the diameter of its bore) is expressed in inches or millimeters. For all guns of caliber 3-inch and above, the length of the gun barrel is customarily expressed by dividing the length of the bore plus the length of the chamber by the diameter of the bore. Thus a 3"/50 caliber gun barrel has a caliber of 3 inches and is 50 calibers or 150 inches long.

Guns are usually designated by (1) their caliber in inches, followed by the length of the gun in calibers and by mark and mod numbers, or by (2) the diameter of the gun in millimeters followed by the mark and mod numbers. Thus there are 16-inch 50-caliber Guns Mark 1 Mod 1, and 40-millimeter Guns Mark 1 Mod 1.

Guns are classified according to bore diameter:

1. Major caliber—8 inches or larger.
2. Intermediate caliber—greater than 4 and less than 8 inches.
3. Minor caliber—greater than 0.60 inch but not more than 4 inches.
4. Small arms—0.60 inch or smaller.

4D5. GUNS IN SERVICE

Guns most likely to be found on Navy ships today are:

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Guns	Carried on
16"/50 cal*-----	Battleships.
16"/45 cal*-----	Battleships.
8"/55 cal-------	Heavy cruisers; guided missile cruisers.
6"/47 cal-------	Light cruisers; guided missile cruisers.
5"/54 cal-------	Large carriers, destroyers, and frigates, tactical command ships
5"/38 cal-------	Battleships, cruisers, destroyers, carriers, and auxiliaries.
5"/25 cal*------	Submarines.
3"/70 cal-------	Frigates and tactical command ships.
3"/50 cal-------	Any ship from patrol craft to battleship.
40-mm ---------	
20-mm ---------	

*In reserve fleet only, not in active fleet.

4D6. SIGNIFICANT FEATURES OF MODERN GUNS AND MOUNTS

The effectiveness of modern guns, as contrasted with the primitive naval weapons mentioned at the beginning of this section, can be directly attributed to the following significant and characteristic features:

1. Improved metallurgy and barrel construction.
2. Rifling.
3. Breech-loading mechanisms.
4. Percussion and electrical firing systems.
5. Recoil and counterrecoil systems.
6. Power-driven ammunition hoists.
7. Power rammers and mechanical ammunition feed.
8. Safety features—salvo latch, safety link, gas ejection.
9. Sighting and fire control equipment.
10. Power drives for elevating and training.

4D7. GUN BARRELS

Figure 4D6 shows in cross section a typical modern gun barrel.

At the rear or breech end of the gun is a breech housing, which houses the breechblock or plug; this can be opened for loading and closed for firing by a breech mechanism of which it is an important part. Just forward of the plug is an enlarged chamber to contain the

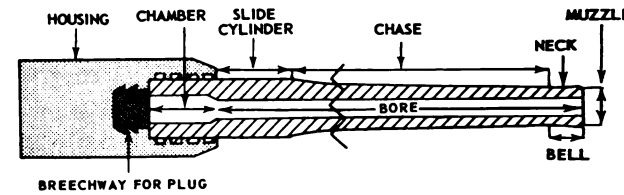

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Figure 4D6.—Main parts of a gun barrel. Cross section.

propelling charge. The forward end of the chamber tapers down to the bore, which has a constant diameter to the front or muzzle end of the gun. In all but a few special purpose guns the bore is rifled—that is, a set of spiral grooves is engraved into its surface. In larger guns, which tend to wear more rapidly per round fired than smaller weapons, the rifling is cut in a liner which can be replaced when worn.

The bulkiest part of the gun is at its breech end, where the metal is thickset to withstand high propellent gas pressures. The cylindrical after part of the barrel is the slide cylinder, which moves in bearings in the slide during recoil. Forward of the slide cylinder the barrel tapers (this tapering part is the chase), then (in many gun designs) thickens to form a bell, which discourages any tendency for the metal to split. The narrow part of the barrel just abaft the bell is the neck. In newer gun designs the muzzle has no bell, but may have lugs which serve to anchor a jack used in replacing the liner.

All modern gun barrels are of steel, and they are generally prestressed to make them more resistant to internal pressures. Prestressing methods will be discussed in further detail in a later section.

4D8. RIFLING

Early cannon were smoothbores and generally fired round (spherical) shot. Other things being equal, a light projectile will travel a lesser distance, and be more affected by wind and air resistance, than a more massive one. Since the maximum volume of a sphere depends on its radius, the mass of the early gun projectile was limited by the density of its material. An elongated projectile can, of course, be made more

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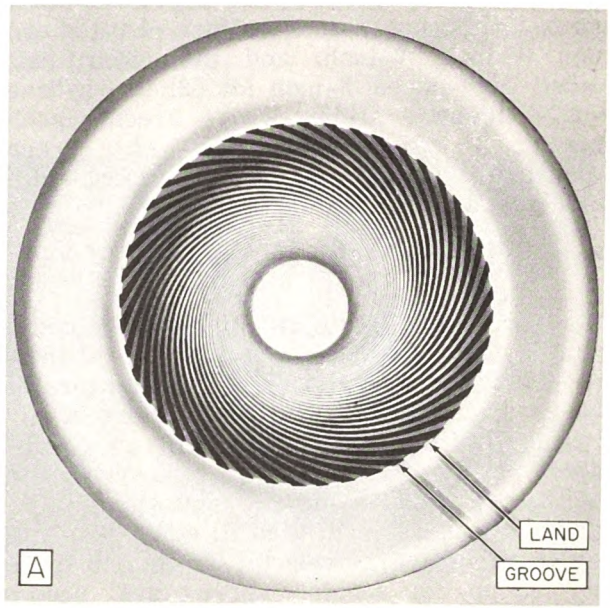
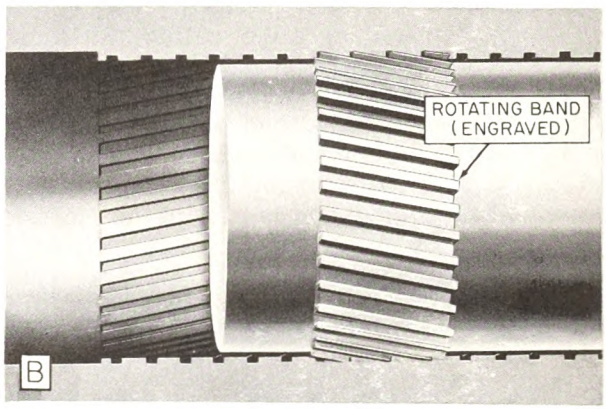
massive by making it longer, but it will be unstable and erratic in flight—unless it can be made to spin on its long axis.

Figure 4D7 shows how this problem is solved in a modern naval gun. The projectile is elongated, with an ogival forward end. The gun bore is rifled, and the rifling grooves are helical or spiral (fig. 4D7, part A). In all naval guns and small arms except the .45 caliber pistol, the rifling has a right-hand twist. The twist may be uniform (generally around 1 in 15 or 20 times the bore diameter), or increasing (as in the 40-mm gun) so that the twist becomes sharper as it nears the muzzle.

The caliber of a rifled gun is measured from the top of one land (the high surfaces between grooves) to that on the opposite side of the bore. Since the rotating band for the projectile is slightly larger than the nominal gun bore diameter, the rifling cuts into or engraves the softer metal of the rotating band when the projectile is rammed (fig. 4D7, part B). When the gun is fired, the projectile spins at an increasing rate as the propellent gas accelerates it. (With right-hand twist in the rifling, the spin is clockwise as viewed from the breech.) Moreover, because of the close fit between rotating band and rifling, the gas is sealed behind the projectile. Figure 4D7, part C, shows how a projectile might look as it leaves the muzzle, spinning rapidly and with rotating band deeply engraved.





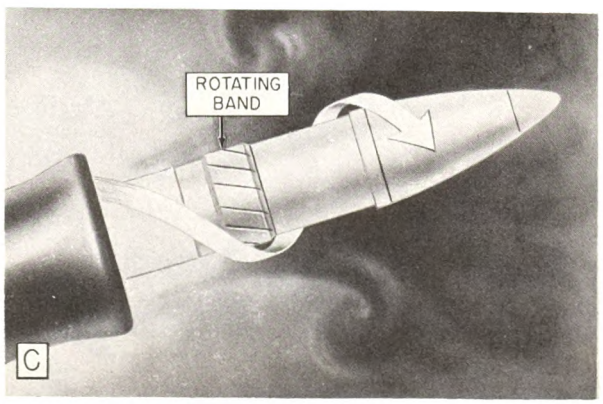


Figure 4D7.—Rifling. A. Rifled bore (viewed head on). B. Rifling engraves the rotating band. C. Projectile spin in flight. 84.143

4D9. BREECH MECHANISMS

The breech mechanism comprises the breechblock or plug that closes off the after end of the gun, and the linkages and other mechanical parts required to operate it. The breech mechanism, as it happens, invariably incorporates part of the firing system.

All naval guns other than small arms (which are not taken up in this book) utilize one of two principles of operation in their breech mechanisms. The older, and nowadays by far the less used, is the interrupted-screw breech mechanism. The newer is the sliding-wedge breech mechanism.

Only bag-type guns use the interrupted-screw breech mechanism in today's Navy, and only a few heavy cruisers (Baltimore and Boston class) in the active fleet have bag guns. (Other types of vessels equipped with bag guns are in the reserve fleet at present.) This type of breech mechanism will therefore not be described in this course. Sliding-wedge breech mechanisms

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are used in all present guns larger than small arms, up through 8-inch caliber. Larger case guns (6-inch, 8-inch, and the automatically loaded high-speed 5-inch Mk 42) use hydraulically actuated sliding-wedge breech mechanisms; in others the sliding-wedge breech mechanism is driven through camming action during recoil and counterrecoil.

4D10. FIRING SYSTEMS

Figure 4D8 shows the principal common firing system elements that are housed in the breechblock of a case gun 40-mm or larger. The 40-mm mechanism and the mechanisms of a few obsolescent hand-loaded 3-inch guns are capable only of percussion fire, 5-inch guns earlier than Mk 42 are capable of either percussion or electrical fire as desired, and all other case guns now in service are designed for electrical fire only (except for special "short cases" used to clear a gun by percussion fire in an emergency).

Common to all case gun firing systems is the firing mechanism (also called the firing lock) in the breechblock (fig. 4D8). This is secured in the breechblock, but is not considered part of the breechblock, and is easily removed for servicing or replacement. In combination and electric firing systems the firing pin is electrically insulated and is part of the electric firing circuit. The pin makes contact with the primer of the loaded propelling charge case when the gun is loaded and the breech is fully closed. The pin is withdrawn into the breechblock when the breech is not fully closed. In combination and percussion firing systems the firing pin can deliver a blow on the primer when actuated by a mechanical firing linkage, provided the gun is in battery, and the breech is fully closed.

ELECTRIC FIRING CIRCUITS. The firing mechanism proper—which has as electrical elements only an insulated firing pin and a quick-disconnect terminal to which a firing lead or cable is attached—is only the final part of the electrical firing system.

Figure 4D9 shows schematically the elements that will be found in a typical electrical firing system for a mount or turret. The diagram does not show the physical locations or appearance of the elements.

Under normal service conditions, guns fire by using the ship's 115 VAC supply. Trace the circuit beginning with this source. Switches (not shown on the schematic) in the fire control plotting room (plot) determine where control of remote fire will be placed. That is, whether the director or plot has control. There are spring-loaded normally open firing keys at each station which can assume control. These are all on the 115-volt line to the primary of the firing transformer at the mount. The mount captain, when told to do so, operates his firing selector switch to the "plot" (meaning remote) or to the "local" position. In "local" the primary supply is always present in the firing transformer.

The firing transformer's secondary feeds 20 VAC to a firing selector switch at the mount. This switch has two positions, "battery" and "motor-generator." Batteries in these circuits, while still part of the schematic, are no longer installed due to the extra maintenance they require. So, this firing selector switch will always be in the motor-generator position except during maintenance.

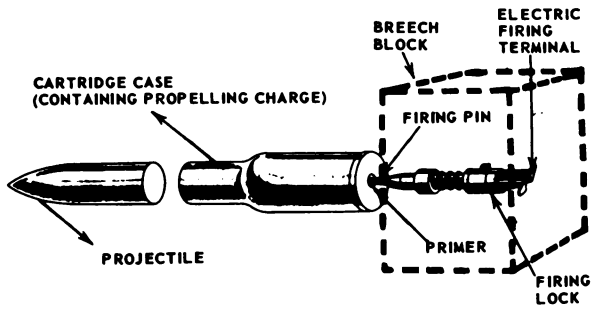

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Figure 4D8.—Sliding-wedge breech elementary firing mechanism.

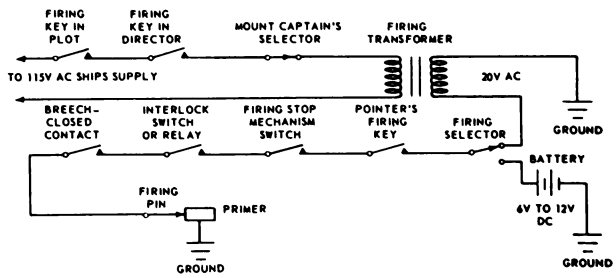

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Figure 4D9.—Representative electrical firing circuit. Schematic.

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The pointer's firing key is generally on one of the elevating handwheels, and is connected to the circuit by a flexible cable. The firing stop mechanism switch is part of the firing stop mechanism (to be described later). It opens the firing circuit when the gun endangers part of the ship's structure. Some mounts have no interlock switch or relay, but such interlocks are common with automatic loading equipment or hydraulically operated breech mechanisms. The one shown in the schematic may represent up to six or more, each of which registers that a certain mechanism or part is in a position that is safe for firing. The breech-closed contact is a common variety of interlock. In addition (and not shown in the schematic) are the safety devices in breech and firing mechanisms which prevent contact between primer and firing pin when the breech is not fully closed or the gun is not fully in battery.

The last part of the circuit is the firing pin's contact to the electric primer. The circuit is completed through the filament in the primer, the cartridge case, and ground return to the firing transformer.

FIRING STOP MECHANISM. At any considerable range, the axis of a gun's bore deviates from the line of sight to the target. The greater the range, the greater the deviation. This makes it possible, particularly in enclosed mounts, for a pointer or trainer looking through a telescope to see no obstacle in the line of sight, while the gun's bore may be in line with some part of the ship's structure, so that firing the gun will damage the ship. It is therefore necessary either to prevent pointing the gun bore toward the ship's structure, or to prevent it from firing under these conditions. The latter method is more common. This is the function of the firing stop mechanism, which disables the firing system when the gun is so aimed as to endanger the ship it is mounted on.

Figure 4D10 shows the basic mechanism. It is essentially a plate or disc type cam, in which the inputs are gun train (which rotates the cam) and gun elevation (which moves the cam follower approximately radially across the cam). The elevation input shaft moves toward the center of the cam plate when the gun elevates, and toward the edge when it depresses. At the end of the elevation input shaft is a spring-loaded plunger which contacts the cam plate. Each point on the surface of the cam plate corresponds to a specific position (in train and elevation) of the gun barrel; the complete surface is a profile map of the gun's safe and unsafe firing areas.

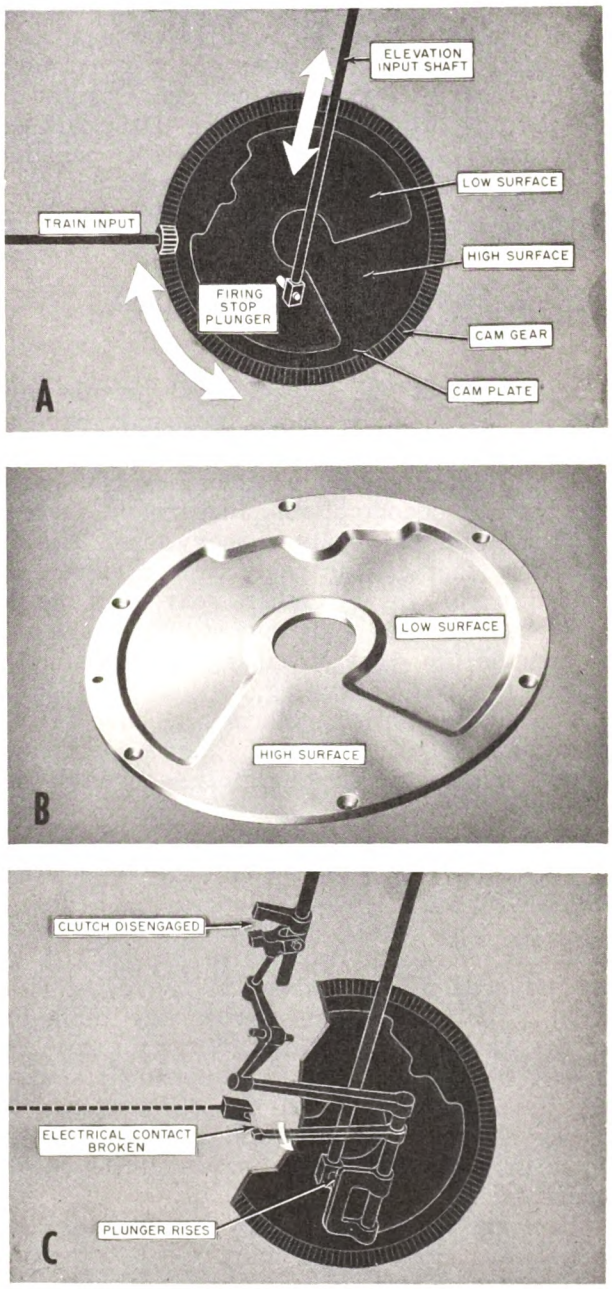

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Figure 4D10.—Principle of firing stop mechanism. A. Mechanical inputs. B. Profile cam plate. C. How fire is interrupted.

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When the gun mount is installed, part of the cam plate surface is cut away so that when the gun is in a position where it is safe to fire, the spring-loaded cam follower plunger will be depressed, while in unsafe positions of the gun (i.e., aimed at the ship) the plunger will be forced upward. Thus the cam plate areas corresponding to safe firing positions are cut away, and the unsafe areas are not cut. Chapter 9 explains how this is done. Figure 4D10, part C, shows how plunger action can both open the electrical firing circuit and interrupt the percussion firing linkage (if there is one) when it is riding on a high area of the cam.

4D11. RECOIL AND COUNTERRECOIL SYSTEMS

Novels about life aboard naval vessels of a hundred years ago or more frequently have a scene in which a naval gun mount breaks loose—either in battle, during a storm, or both—and thunders, an uncontrollable Juggernaut, across the deck as the ship rolls in heavy seas. This is something that can scarcely happen aboard a modern naval vessel; other gear may break loose, but how can a gun mount? Why were not the guns in the days of sailing vessels simply secured to a fixed mounting, as guns are today?

The answer is that modern guns have recoil and counterrecoil mechanisms, and ancient guns did not. A naval gun can be rigidly secured to the deck, but without some provision for its recoil it will break loose when fired.

Note the general functions of recoil brakes and counterrecoil mechanisms:

1. A recoil brake is primarily designed to absorb the force of recoil and "spread" it so that the sudden heavy shock is converted to a thrust exerted over an appreciable distance through which the recoiling parts of the gun are permitted to move. In the mechanical sense, work is done by the recoil force in pushing the gun and housing aft against the resistance of the recoil brake; the energy absorbed in the brake appears as heat.

a. A secondary function of all recoil brakes in naval gun mounts is to bring to a smooth stop the forward movement (counterrecoil) that follows recoil.

2. A counterrecoil mechanism is a device that stores some of the energy of recoil and uses it to force the recoiling parts forward into battery after the projectile has left the gun muzzle. (The energy of recoil can, of course, be traced ultimately to the combustion of the propellant.)

Recoil and counterrecoil mechanisms are designed to work together. Figure 4D11 shows in a general way where the recoil and counterrecoil systems are located in a conventional 5-inch mount.

There are many different types of recoil and counterrecoil mechanisms used in land artillery and elsewhere. The U.S. Navy uses in naval gun mounts one general type of recoil brake (in either of 2 variants), and two kinds of counterrecoil mechanism.

RECOIL SYSTEMS. All present day recoil systems for naval guns larger than 20-mm use hydraulic recoil brakes. A hydraulic recoil brake is a mechanism of the type commonly termed by engineers a "dashpot." Its piston and a cylinder can move with respect one to the other. The liquid in the cylinder can move from one side of the piston to the other, but its rate of movement is restricted or "throttled."

The two variants of this device are shown in figure 4D12. In one variant (A in the figure), the piston is solid, and each cylinder is filled with recoil fluid (usually a mixture of water with glycerin). In the wall or liner of each cylinder are cut three throttling grooves 120° apart. They are shallow at the forward end of the cylinder and deepen toward the after end.

The principle of functioning of the throttling-groove type (A in the figure) was described in chapter 3. The other major type of recoil brake

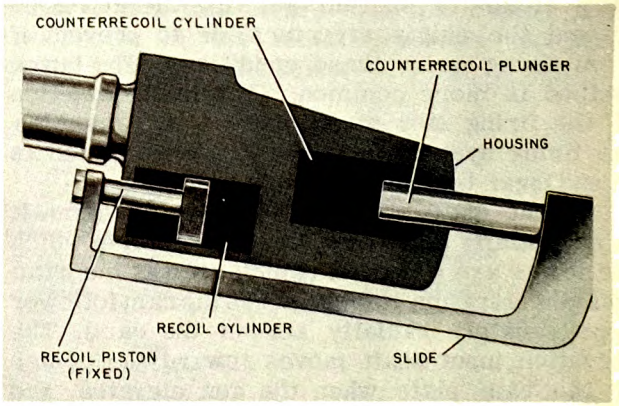

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Figure 4D11.—Recoil and counterrecoil systems in a conventional 5-inch mount. Simplified schematic.

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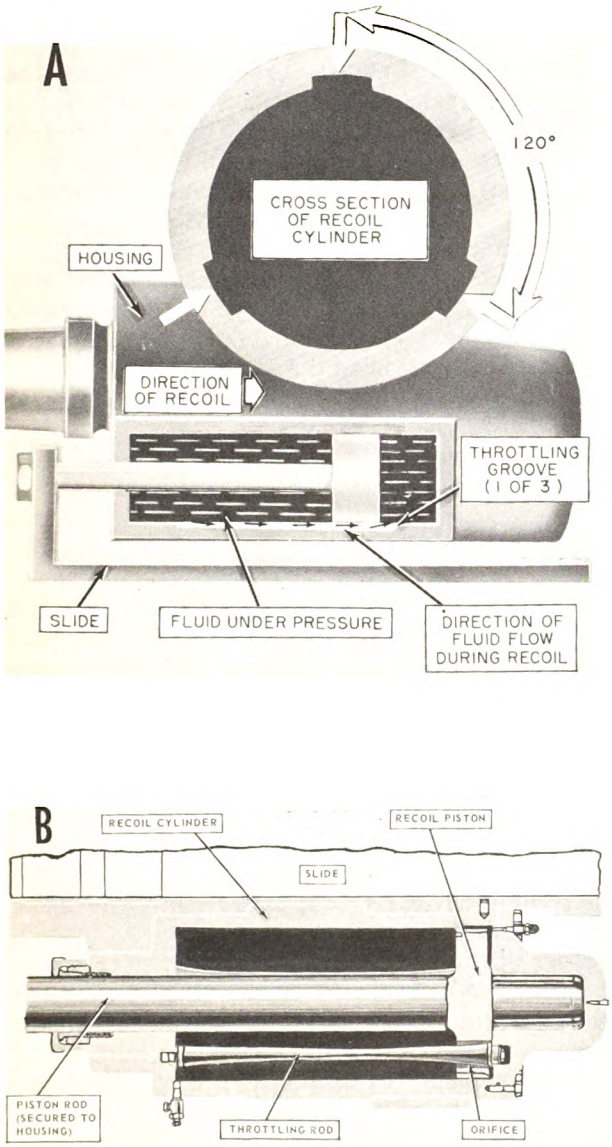

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Figure 4D12.—Hydraulic recoil brakes. Simplified schematic. A. Throttling-groove type. B. Throttling-rod type.

(part B of figure 4D12) uses three fixed tapered throttling rods which pass through orifices or holes in the piston. (Only one rod is shown in the figure.) This arrangement functions like the throttling-groove brake, except that the fluid flow is regulated by the varying cross section of the rods in the holes.

COUNTERRECOIL SYSTEMS IN GENERAL. There are 2 basic types of counterrecoil systems used in United States naval guns. Guns smaller than 5-inch use 1 or more counterrecoil springs. (These are sometimes termed recoil springs in OP's and elsewhere, but the function is the same.) Guns 5-inch and larger use pneumatic recuperators, which depend on compressed gas (generally air or nitrogen) to provide counterrecoil thrust. Since the very high-pressure gas used in such systems is sealed by use of packings under hydraulic pressure, such systems are often called hydropneumatic counterrecoil systems.

The functions of any counterrecoil system are (1) to return the recoiling parts of the gun to battery after recoil, and (2) to hold the recoiling parts in battery. Thus a counterrecoil system must not only provide thrust during counterrecoil, but must also develop enough continuous thrust at all times to hold them there except while the projectile is actually being propelled through the bore. (Recoil brakes develop their "reverse thrust" for braking only while the gun is actually moving in recoil, and at other times exert no forces on the gun parts.)

Because its thrust "follows through" to the end of the counterrecoil stroke, any counterrecoil system tends to drive the recoiling parts into battery with considerable shock. Hence all counterrecoil systems for guns 40-mm and up must have a counterrecoil buffer to take up this terminal shock.

SPRING COUNTERRECOIL SYSTEMS. In all naval guns smaller than 5-inch, coil springs provide counterrecoil thrust. In late 3"/50 mounts and most 40-mm mounts, the springs surround the exterior of the barrel.

HYDROPNEUMATIC COUNTERRECOIL SYSTEMS. A pneumatic counterrecoil system requires a cylinder or bore (in the housing) charged with inert gas (generally nitrogen or air, never oxygen or other chemically active gas). Gas pressure in a conventional 5-inch system is around 1,500 psi. A plunger (fig. 4D11) fitting into the after end of the housing is forced to the rear by the gas pressure against the after end of the slide. The thrust exerted by the plunger against the slide holds the housing in battery and returns it to battery after firing.

The complication of this arrangement lies in the packing which surrounds the plunger in the housing. Ordinary packing, unsupported, will not withstand the gas pressure in the counterrecoil chamber. Therefore the packing used is

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a chevron type "inflated" by oil under pressure (fig. 4D13). The oil pressure in the packing is always higher than that of the gas in the cylinder. The device that ensures this pressure relationship is the differential cylinder. Chapter 3 explains in detail the principle of this device. Gun mount maintenance personnel inspect the cylinder daily, and pump additional oil in if the rod protrudes more than three inches.

Counterrecoil buffers are dashpot devices used to control the velocity and cushion the impact of counterrecoiling parts at the end of counterrecoil. In present designs, they are physically located in the recoil mechanisms, and incorporate needle valves which can be adjusted (within limits) to modify the speed of the counterrecoil stroke.

4D12. AMMUNITION TRANSPORT EQUIPMENT

The effectiveness of a gun as a weapon depends, other things being equal, on the number of rounds per minute it can put on target. This in turn depends on the efficiency of the personnel and equipment respcnsible for transporting the ammunition from its stowage spaces to the mount and feeding it to the gun.

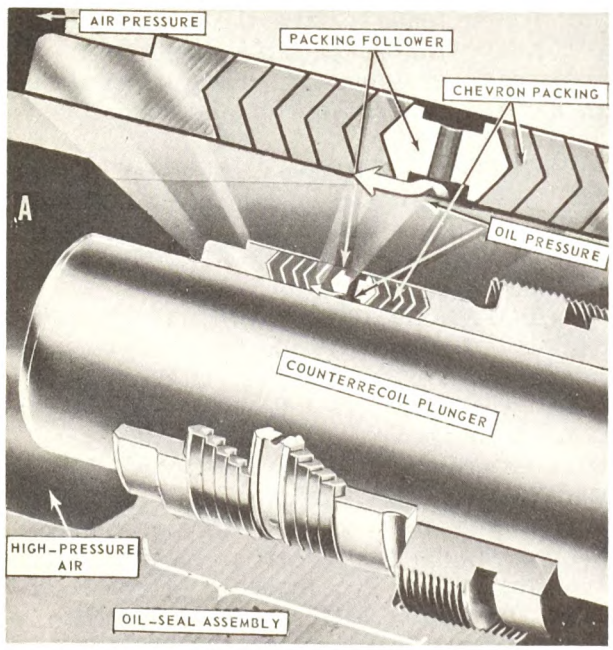

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Figure 4D13.—Hydropneumatic counterrecoil system. Detail of oil-pressure type chevron packing.

Figure 4D14 shows in cutaway form the ammunition transport arrangements for a modern 5-inch twin mount. At the lowest level is the magazine, in which are stacked the propelling charges. The magazine partly surrounds the lower handling room, which is separated by a flameproof bulkhead from the magazine. Powder cases stored in the magazines are passed by hand through scuttles in the magazine bulkhead to the lower handling room. (Projectiles are normally stored in the lower handling room itself, in racks in the upper handling room, and on the gun-house bulkheads.)

The powder cases and projectiles are then loaded into the 2 dredger hoists (1 for each of the 2 guns in the mount) which haul them up to the upper handling room. Each dredger hoist handles both projectiles and powder cases.

On the upper handling room deck are located the upper ends of the 2 dredger hoists, and around the central column in the room are mounted the 2 sets of projectile hoists and powder hoists, 1 projectile hoist and 1 powder hoist for each gun. The handling room crew removes the projectiles and powder cases from the dredger hoists, loads projectiles into the projectile hoist, and loads the powder cases into the powder hoists. Fuze setters in the projectile hoists automatically set the projectile fuze during hoisting.

Most of the propelling charges are stored in the magazine, and most of the projectiles are stored in the lower handling room. To begin ammunition service without delay, a number of complete rounds are maintained in ready racks in the upper handling room. For long periods of sustained fire, however, the entire ammunition supply system must be in action.

All hoists are driven by electric-hydraulic power units.

4D13. AMMUNITION FEED EQUIPMENT

Ammunition feeding and loading devices on the gun or at the gun deck level include power rammers, slide-mounted ammunition loading gear, and equipment used to transfer ammunition from ammunition hoists to the gun slide. These vary considerably in design from one type of mount to another.

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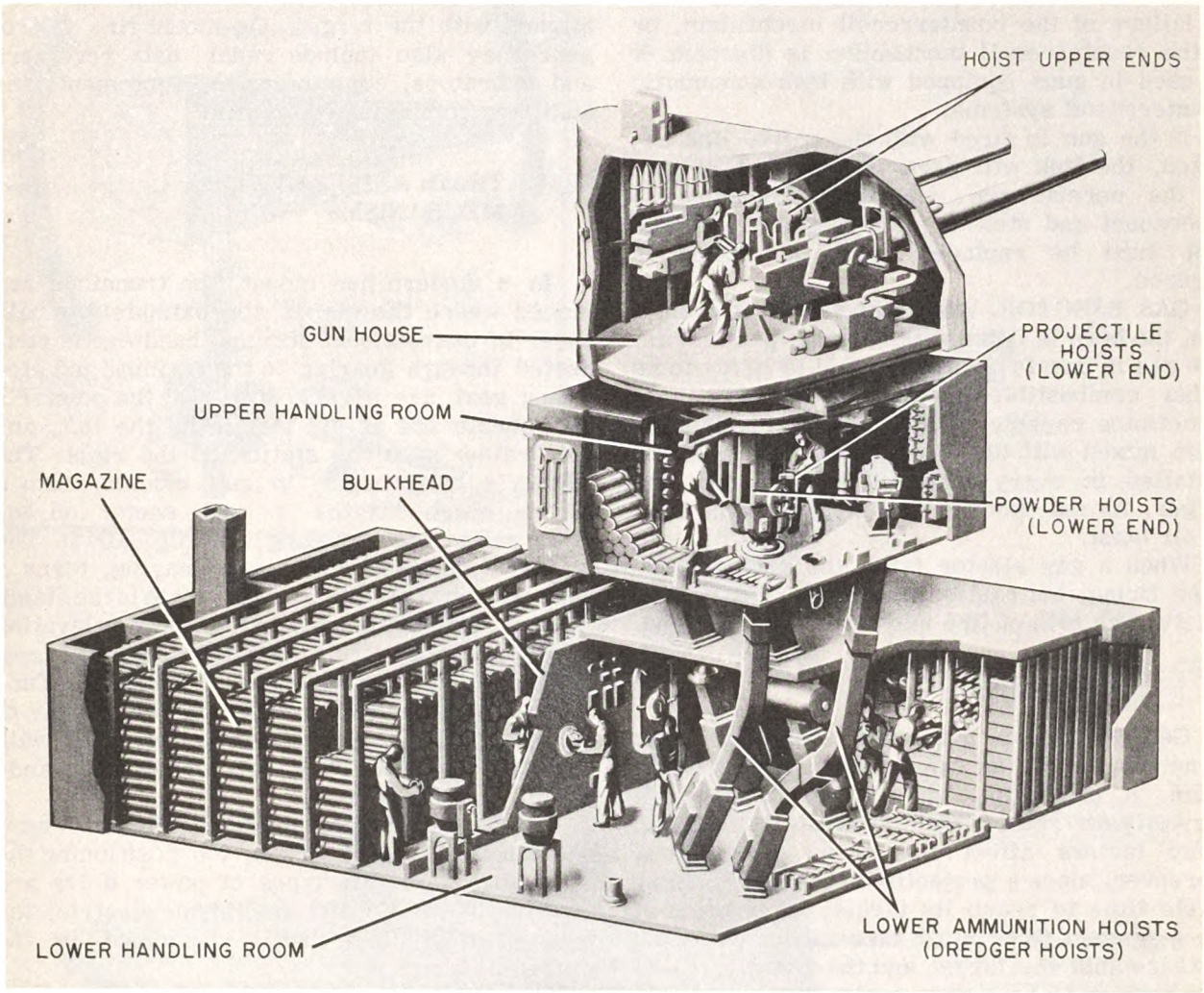

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Figure 4D14.—Ammunition supply system for 5"/38 twin mount.

4D14. MISCELLANEOUS SAFETY FEATURES

Some of the safety features of modern gun mounts and turrets have been taken up in connection with the other mechanisms or systems discussed above. But several additional noteworthy ones are briefly discussed below:

SALVO LATCH. This is a device that locks the breech closed. It can be opened only by deliberate effort. Its function is to prevent accidental manual opening of the breech in event of misfire (i.e., an apparently unsuccessful attempt to fire). The reason for this is explained in the safety appendix of this book.

Salvo latches are part of the breech mechanisms of all guns larger than 40-mm, except for the very newest designs of automatically loaded guns like the 8-inch case gun used in Salem class turrets.

The salvo latch is a positive lock cammed to open automatically during recoil. It will not open automatically if the gun does not recoil.

SAFETY LINK. The safety link is a metal strip that couples the breech yoke (in bag guns)

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or housing (in case guns) to the slide. It is intended to hold the gun in battery in the event of failure of the counterrecoil mechanism, or if the counterrecoil mechanism is disabled. It is used in guns equipped with hydropneumatic counterrecoil systems.

If the gun is fired with the safety link engaged, the link will part. However, it is part of the normal gun operating procedure to disconnect and stow the link before firing. The link must be replaced when the mount is secured.

GAS EJECTOR. When a shot is fired from a gun, the bore is filled with residual powder gas. The gas is unsafe to breathe, and is likely to be either combustible or actually burning; it is sometimes capable of spontaneous combustion when mixed with air. The gas ejector, which is installed in every enclosed mount 5-inch and larger, forces this residual gas out of the bore by air blast.

When a gas ejector fails, the gun can continue firing, but caution is necessary to ensure safety. The rate of fire may have to be reduced.

4D15. SIGHTING AND FIRE CONTROL EQUIPMENT

Getting the gun projectile to hit its target is not as simple as aiming, say, a searchlight beam. A projectile, when fired, travels in a curved path rather than a straight line, and many factors affect the shape of its path. Moreover, since a projectile requires an appreciable time to reach its target, the position of the gun when fired must take into account the distance that the target and the gun will travel with respect to each other during the projectile's flight. To do this requires that all these data must be measured and their effects solved mathematically so that the solution indicates how the gun must be positioned for the projectile to hit the target.

The techniques for doing this are called, collectively, fire control. There will be more details on them later in this course. Most of the fire control work is done elsewhere than on the gun mount, but the gun mount does incorporate certain fire control gear—notably the sights. Sights are optical devices which can be used to position the gun with respect to a straight line (the line of sight or LOS) from the gun to the target. Certain more complex sighting equipments (called lead-computing sights) incorporate computing mechanisms which automatically establish gun position with respect to the LOS while a crewman on the gun mount is tracking the target (i.e., keeping the LOS aligned with the target). On-mount fire control gear may also include radar, data receivers and indicators, communication equipment, and auxiliary computing equipment.

4D16. TRAIN AND ELEVATION MECHANISMS

In a modern gun mount, the trunnions are placed where the gun is approximately in balance. In conventional designs, handwheels connected through gearing to the training and elevating gear are arranged so that the pointer's handwheels are at his station on the left, and the trainer's at his station on the right. The pointer's handwheels, in gun mounts, turn a pinion which rotates a gear sector on the slide called the elevating arc (fig. 4D15). The trainer's handwheel, through gearing, turns a gear that engages the training circle in the stand.

In turrets using bag ammunition the elevating gear turns an elevating nut which engages a screw pivoted to the gun slide (fig. 4D15 inset). Turrets using case ammunition must be capable of much greater elevations than are practical with this arrangement. They therefore use arc-and-pinion elevating gear.

All turrets, and mounts larger than 20-mm, normally use power drives for positioning the gun. The two main types of power drive are electric-hydraulic and amplidyne electric; the principles of these were described in the preceding chapter.

The conventional arrangements described above in this article do not apply in the newest mounts. For example, in the automatically loaded 3"/50 mounts, the gun cannot be manually elevated and trained from the gun-laying stations on either side of the mount. The controls there provide only for operating the mount through the power drives. The left gun layer's station is used for positioning the mount when firing on air targets; the right gun layer's station is in control for surface targets. Either station, or the director, may be in full control. When either gunlaying station is in control, mount train and elevation are both controlled by that station. Hence there is no "pointer's" station or "trainer's" station on this mount. And manual elevations and train are used only for positioning the mount for maintenance or alignment-checking purposes.

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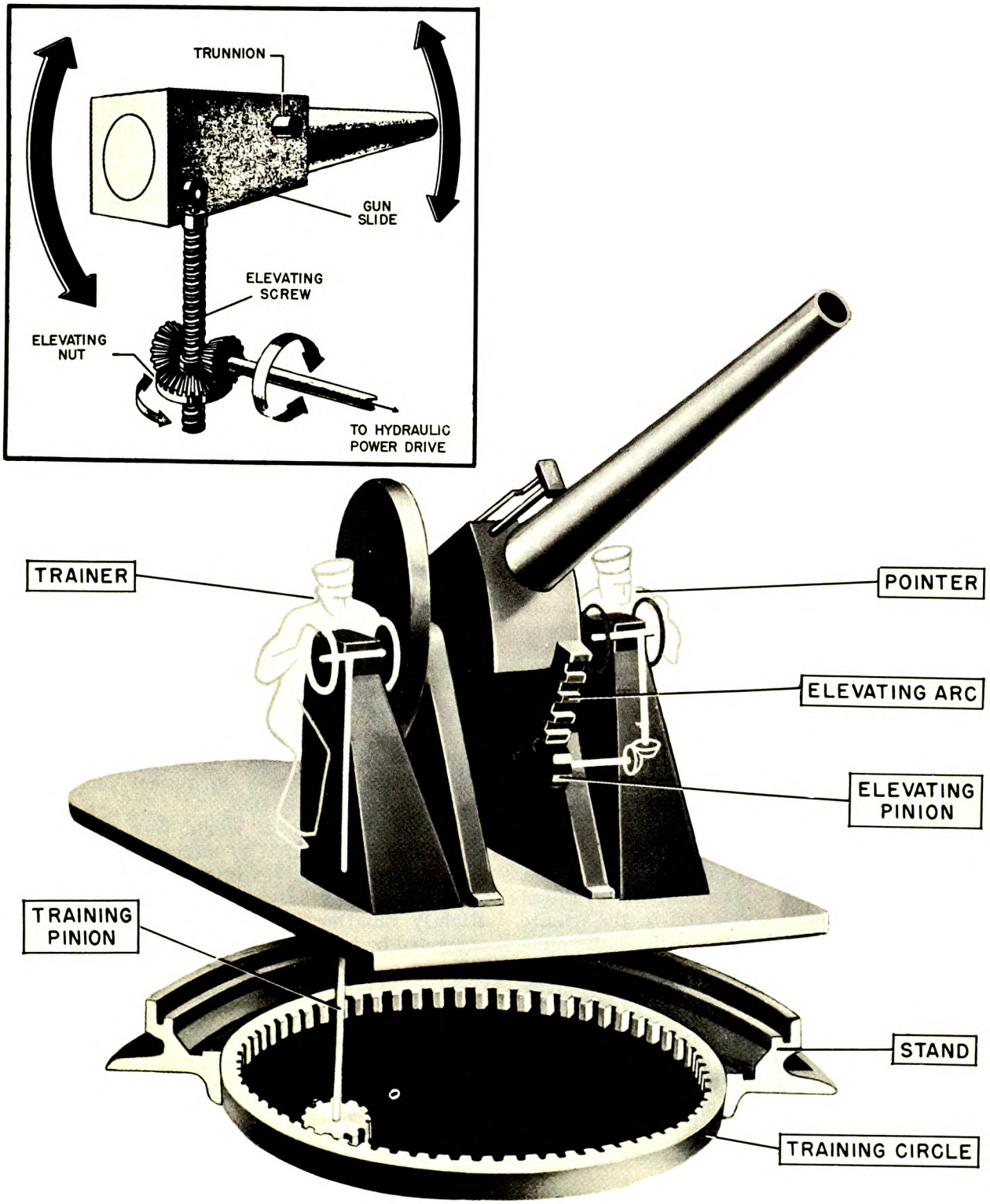

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Figure 4D15.—Training and elevating gear (simplified). (Insert: Screw-type elevating gear.)

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E. Gun Barrel Construction and Maintenance

4E1. INTRODUCTION

Commonly, the term gun applies to the entire assembly of which the barrel is but one part. In this section, gun, tube, or barrel designates the gun tube only, and not the remainder of the gun assembly.

4E2. ESSENTIAL REQUIREMENTS OF A GUN

A gun may be considered as a tube designed to withstand a given pressure from within. In constructing such a tube, we must first consider what pressures it will have to withstand at the various points of its length, and then make it strong enough to insure perfect safety. The bore should also be of such material as to stand the wear and tear of firing a large number of rounds without being so damaged by expansion or abrasion as to interfere with the shooting.

4E3. STRESSES IN A GUN CYLINDER

Considering a gun only as a cylinder, we find that the two principal stresses (fig. 4E1) to which such a cylinder is subjected upon firing are:

1. A tangential stress or tension, coupled with a radial stress, tending to split the gun open longitudinally.
2. A longitudinal stress tending to pull the gun apart in the direction of its length.

Experiments have shown that the greatest stress on the metal of the gun is the tensile stress set up in the direction of its circumference by powder gas pressure. In addition, the gun also experiences a longitudinal stress of relatively small value. If this longitudinal stress may be considered constant (and in guns it may be so considered without great error) we may lay down "Lamé's law," as follows:

At any point whatever, in a cylinder under fluid pressure, the sum of the tangential tension and the radial pressure varies inversely as the square of the radius.

This law says, in effect, that in a simple hollow cylinder under internal pressure, points in the metal close to the bore experience a large proportion of the stress, whereas those at a greater radius experience only a small proportion. Thus in a simple hollow cylinder of homogeneous metal, we soon reach a limit beyond which any thickness of wall aids but little in enabling the cylinder to withstand pressure.

Because of this severe limit on the strength of a simple hollow cylinder, however thick, guns must be built on a principle which will enable them to withstand more internal pressure than would be possible with the simple cylinder construction. The problem is to make the outer layers take a proper proportion of the stress.

4E4. METHODS OF GUN BARREL CONSTRUCTION

It is possible to make the outer layers of metal in the gun barrel bear a greater share of the load by prestressing the gun tube. There are two types of gun construction using this principle—built-up construction and radially expanded construction.

The "built-up" method of prestressing is to heat steel ring-shaped jackets, or hoops, to high temperatures, then slip them over the gun tube and allow them to cool. As the hoops cool, they contract, until at the end of the process they squeeze the gun tube with a pressure of thousands of pounds per square inch. Guns so constructed have been in recent years made only in sizes over 8-inch.

About the time of World War I, the same principle was applied to monobloc (one-piece) guns in the radial-expansion or autofrettage process. In this process, a gun tube with bore slightly smaller than the caliber desired is expanded by hydraulic pressure. When the pressure is released, the outer layers of the tube tend to return to their original dimensions, while the enlarged inner layers tend to maintain their enlargement. Thus the inner layers of metal are severely compressed by the contraction of the outer layers, as if a hoop had been shrunk on.

The built-up and radially expanded methods may be incorporated in a single gun. The 8"/55 caliber gun, for example, has a jacket shrunk on a radially expanded tube.

Smaller guns are made from a single steel forging with neither radial expansion nor hoops. The pressures in small guns may be higher

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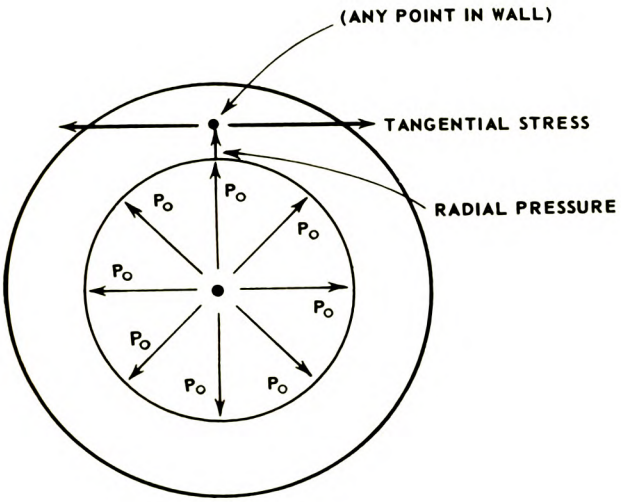

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Figure 4E1.—Tangential and radial stresses in a gun cylinder. Schematic.

than in large guns, but the forging, which is not excessively large in any event, can be made bigger. This type of construction is, at the present time, limited to guns of 3-inch caliber and smaller.

4E5. DETERIORATION IN THE GUN BORE

The "working surfaces" of the gun are the interior of its bore and chamber. As time passes, and as round after round is fired, these surfaces will deteriorate, and maintenance is required to ensure their continued usefulness. The main causes of deterioration are (1) erosion, (2) corrosion and dirt, (3) copper fouling, and (4) constriction.

4E6. EROSION

CAUSES. Erosion is the deterioration and wearing away of the bore surface caused by firing projectiles through it. Erosion is not merely the direct effect of friction which causes the bore surface to wear away as the projectile passes through. The exact mechanics of erosion are not known with precision, but the following are recognized as the principal causes:

1. The bore surface becomes intensely heated in firing, and the rush of hot gases across this hot metal has a scouring effect.

2. The hot powder gases react with the metal, changing the carbon content on the surface of the bore. Since this surface is designed with an optimum carbon content, any change results in a weakening of the metal.

3. The alternation of intense heat and rapid cooling affects the temper of the metal.

4. The propellent gases are forced into and out of the pores in the metal surface as they open and close during the expansion and contraction which accompanies such drastic temperature changes.

5. Heat cracks may develop.

6. Gases escaping around the projectile act as high-velocity jets, scouring the bore and causing damage, especially where there are heat cracks.

EFFECTS. Erosion is always greatest at the origin of rifling (fig. 4E2), and the tops of the lands wear away faster than do the bottoms of the grooves.

Erosion at the origin of rifling, in guns using semifixed ammunition, tends to permit the projectile to seat farther and farther toward the muzzle. This reduces the density of loading (this term is explained in the next section of this chapter) and therefore the I.V. (initial velocity). In guns using fixed ammunition, this effect does not apply, but in all guns erosion at the origin of rifling permits gas to escape around the projectile, and this in turn increases erosion.

As the lands wear, not only does more gas escape around the projectile but the rifling engraves the band less deeply, reducing materially

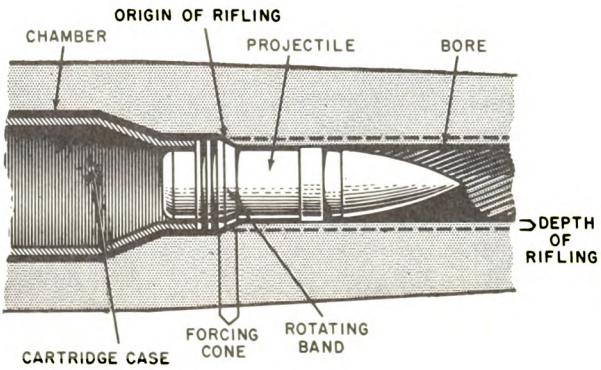

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Figure 4E2.—Erosion areas in a gun chamber and bore.

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both the initial forcing pressure and the resistance of the projectile to the gas pressure. The effect is a material drop in muzzle velocity.

CONTROL OF EROSION. All erosion factors are related to (1) the temperature of the expanding gases and (2) the duration of their confinement in the bore. Hence larger guns, with their slower powders and longer barrels, suffer more erosion per round fired than smaller guns. On the other hand, smaller guns have a higher firing rate, which permits less cooling time between rounds.

Chromium plating of gun bores has reduced the effects of erosion; the use of molybdenum will probably make for even better erosion resistance in the future.

Some smaller guns are cooled by water jackets around the barrels, and there have been experiments on introducing a coolant between the tubes and the liners of larger guns. Also under development are cooler propellants. Any development that reduces the heat of explosion will aid in erosion control.

EROSION MEASUREMENT. There are, for each class of gun, data sheets furnished to ships showing relationship between the enlargement of the bore and the initial velocity to be expected from the gun. The data sheets show this information in the form of plotted curves. If the actual diameter is frequently checked, velocity loss becomes predictable, proper allowance for it can be made in aiming, and barrels or liners may be replaced before their performance becomes noticeably erratic.

In some minor-caliber guns, measurements of bore enlargement is made at the origin of rifling only. This is done with a wear gage, which is a truncated cone that can be inserted directly in the breech. In larger guns, erosion is measured at several points in the bore with a star gage.

The star gage (fig. 4E3) consists of a head mounted on a long tube, with metal points 120° apart extending radially from it. These three points form a Y and press against the bore of the gun. Points of suitable length are provided for each caliber of gun to be measured. The bases of the points are spring-loaded to bear against a tapered expanding plunger; as the plunger (operated by the vernier lever) moves lengthwise, the points are cammed outward or inward. Measurements are read from the vernier scale.

VELOCITY LOSS ESTIMATION. Stargaging is performed by highly skilled personnel in tender or shore-based facilities. The object is to measure the amount of erosion along the bore (and especially its origin) so that the corresponding predicted loss in I.V. can be included in the fire control solution. Tables, charts, graphs, and equations are provided in OP 551, 3rd revision, to convert erosion losses

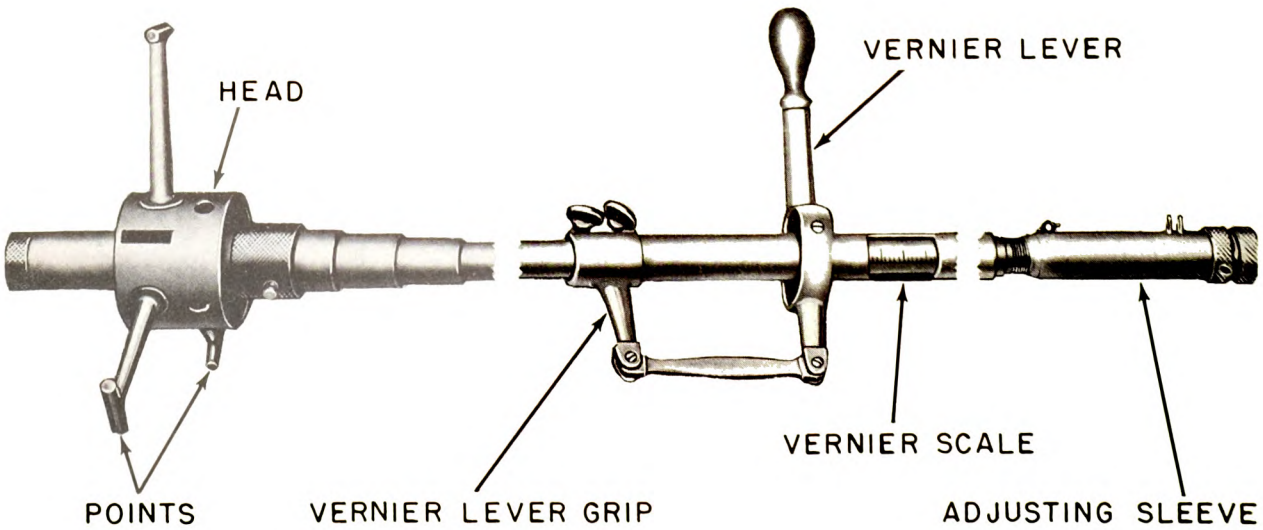

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Figure 4E3.—Star gage.

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into usable I.V. information. While this particular OP is for a 5"/38, there is a similar publication for each type of gun.

Obviously, since stargaging is done in port, and ships are usually at sea, a stopgap is necessary to compute the correct I.V. The stopgap is called EQUIVALENT SERVICE ROUNDS (E.S.R.). Immediately upon receipt of stargage data, the ship converts these data into an E.S.R. for each gun so gaged. The gun ESRs for a battery are then averaged, the applicable OP is consulted for conversion factors, and the resultant I.V. is set into the computer which serves the battery. This is a usable I.V. only so long as no rounds are fired from the battery. As soon as more rounds are fired another quantity must be added to the I.V. computation. That quantity is called PSEUDO EQUIVALENT SERVICE ROUNDS (P.E.S.R.). P.E.S.R. comes from estimates which are based on the fact that each round fired causes a certain amount of erosion. Projectiles which are propelled by full-service powder charges are counted as one P.E.S.R., while reduced-charge firing may be equivalent to about 1/6 of a P.E.S.R. per round fired. (The Navy uses reduced charges for reverse-slope firing.) P.E.S.R. is added to E.S.R. for I.V. computation, but kept separately in records so that comparison can be made with the E.S.R. from the next stargaging. That is, was the P.E.S.R. an accurate estimate of the actual erosion?

Without periodic stargaging, the E.S.R. procedure would not be accurate, mainly because the P.E.S.R. quantity does not reflect the rate of fire. Rounds fired with very short cooling intervals cause more erosion than the same number fired at a normal rate. For practical gunnery, however, this method is considered sufficiently reliable for use.

I.V. MEASUREMENT. At proving grounds gun projectile velocity is measured by a device called a chronograph. The projectile cuts wires when it passes through two successive screens, or it passes through two magnetic coils, and the exact time of each passage is recorded. This yields the projectile velocity between the screens, and from this I.V. can be reckoned.

Chronographs require special setups of coils or screens, careful gun placement and aim, much auxiliary equipment, specially skilled technicians, and a good deal of time. They are consequently not practical for shipboard use. But because erosion and I.V. are significant factors in fire control, the Navy has developed devices on far different principles which can actually measure the velocities of service rounds fired on shipboard. One such design incorporates the velocity-measuring device in a fire control system. In the other, the chronograph device (which works on a different principle from those already mentioned, since it measures projectile velocity in the gun bore) is mounted in the barrel and on the carriage as an independent unit.

4E7. CORROSION AND DIRT

Great heat, great pressure, and complicated chemical changes accompany the burning of the propelling charge. Some but not all the residue of the burning is blown out of the muzzle after the projectile. What remains in the gun (powder fouling) is in the form of corrosive salts. Standard procedure is to remove it by washing out the bore with a hot soda solution and applying a thin film of oil before securing until the next firing. Chromium plating of gun bores has reduced the powder fouling problem.

Dirt in a gun bore not only encourages corrosion but is a source of danger if it offers sufficient resistance to the projectile. To guard against accidental admission of dirt, spray, or moisture into the gun, a solid plug called a tompion (pronounced tom-kin), is inserted into the muzzle. This is only a partial solution, because under certain weather conditons considerable condensation accumulates in the bore. In fair, dry weather, tompions are removed to air out the barrels.

Tompions cannot be used under combat conditions; a tompion accidentally left in a gun would be very dangerous if the gun were fired. However, dirt and water, especially salt water, must be kept out of the gun; so canvas or plastic muzzle covers are used. In an emergency, the projectile can be fired through such covers without bursting the barrel, subject to certain limitations. Projectiles with supersensitive nose fuzes cannot be fired through muzzle covers of any sort. In cold-weather operations, when canvas covers may become ice coated, they should be removed before firing.

4E8. CONSTRICTION

More immediately dangerous than corrosion or dirt is metallic constriction of the bore. Before and after each firing, barrels are tested for this condition with a plug gage, which is a

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steel cylinder accurately machined to slightly under the diameter of the bore (fig. 4E4). If the plug gage will not pass through the bore without undue forcing, the nature of the constriction must be determined. If it is caused by an accumulation of copper, it is dealt with as described in the next article. This is the more likely cause. However, constriction can also be caused by distortion of the steel surface of the bore. This has been known to occur in built-up guns. The friction of the projectile on the bore tends to drag the liner along with it. This tendency is resisted by the shoulders of the liner and the tube. With continued firing, the shoulders of the liner tend to override those of the tube, forcing the walls of the liner inward. As with coppering, steel constriction can be removed by lapping and polishing.

Continued firing may also elongate the liner and cause it to protrude from the muzzle. This is not serious. When the extension amounts to as much as half an inch, it is simply cut off.

4E9. COPPER FOULING

Copper fouling is essentially a form of constriction. It consists of metallic deposits on the bore, left behind by the rotating bands of projectiles. Even an amount of copper too slight to impede the projectile will affect its accuracy. Metallic lead foil in the powder charge, while increasing muzzle flash, has been used in some powders to control coppering. The lead serves as a lubricant and discourages new copper deposits, while existing deposits will be abraded by the passing projectile. New propellants incorporate a trace of lead carbonate.

Copper fouling may be removed with an acid treatment, but this is not authorized for shipboard use. Approved mechanical means for de-coppering consist of rubbing with a wire bore brush or lapping head (fig. 4E4). The head is covered with a fine abrasive material and is drawn back and forth at the location of the constriction until the plug gage can be passed through without forcing. Special scraping or decoppering heads, fitted with steel blades, are supplied for certain guns.

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Figure 4E4.—Plug gage (left) and lapping head.

F. Basic Interior Ballistics

4F1. BALLISTICS

Ballistics is the science of the motion of projectiles. It is divided into two branches, interior and exterior ballistics. Interior ballistics is that branch of the science which treats of the motion of the projectile while in the gun. The initial velocity (I.V.) of the projectile is a result of the forces involved in the general term, interior ballistics. Exterior ballistics pertains to the projectile after it leaves the gun. Obviously I.V. is the one value common to both interior and exterior ballistics.

Gun design is essentially a compromise. The gunner wants maximum I.V. for great range and flat trajectory; the designer must consider the strength of his gun and desires minimum wear and erosion. Interior ballistics includes the study of (1) the combustion of the powder, (2) the pressure developed within the gun, (3) the variations in pressures and velocities with changes in any of the "conditions of loading," and (4) erosion of the bore.

4F2. PROPELLANTS AND BURNING RATE

Propelling charges are designed to burn in the chamber of the gun in such a way that they will develop maximum projectile velocity without excessive heat, pressure, or erosion. Ideally, the most efficient propellant for a gun would be so balanced that the charge is entirely consumed immediately before the projectile leaves the muzzle.

To approach this ideal, propellant burning rate must be controlled, so that the propellant will be suited to the specific gun in which it is

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to be used. The dominant factor in determining burning rate of a given propellant composition is the surface area per unit weight of propellant. The greater the area per unit weight, the faster the burning rate. (Other but less significant factors include the percentage of nitration, moisture content, content of volatiles, and the stabilizer used.)

As you know, gun propellent compositions are manufactured as homogeneous cylindrical grains of uniform diameter, length, and number of perforations (fig. 4F1), with larger grains for larger caliber guns. For a given muzzle velocity, larger caliber guns require a slower burning propellant than smaller caliber guns, since the distance the projectile must travel to the muzzle is proportionately longer and the powder must burn for a longer time. Other things being equal, larger grains have smaller area per unit weight, hence slower burning rate.

Propellent powder grains for guns 40-mm and larger have 7 perforations. Since burning rate climbs rapidly in smaller size powder grains, there is only one perforation, or none at all, in grains for calibers smaller than 40-mm.

A propellant's potential is the total work that the gases of combustion could perform while expanding from the solid state to the space they would occupy when fully expanded to atmospheric pressure and when cooled to a specified temperature.

In the average conventional gun, some 60 percent of the potential disappears in muzzle loss; 30 percent is transmitted to the projectile, and all other losses—such as heating the projectile and gun, causing the gun to recoil, and so forth—amount to about 10 percent.

4F3. GUN STRENGTH VS. PROPELLANT PRESSURE RELATIONSHIPS

Figure 4F2 illustrates a basic principle of gun design. The figure may be taken as typical of the strength-pressure relationship in modern guns. Note that the high breech strength is carried well forward of the point of maximum pressure. The gun strength at every point must exceed the powder pressure at that point by an amount that will provide a suitable margin of safety.

The curve as it appears in figure 4F2 shows pressure beginning at a value well above zero. This indicates the pressure build-up that occurs after the propelling charge begins to burn but before the projectile begins to move. (The x-axis in the figure represents projectile movement in the bore, not time or bore length.) The projectile begins to move only after the propellent gas reaches the initial forcing pressure required to initiate movement of the projectile in spite of projectile inertia and the engagement of the rotating band in the rifling.

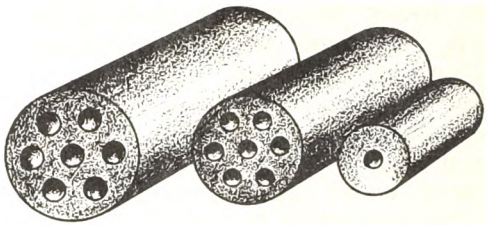

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Figure 4F1.—Perforated propellant powder grains.

Note that the gun strength curve is represented as a straight horizontal line above the area between the point of initial forcing pressure and the point of maximum pressure. It does not vary in parallel with pressure curve. The reason is that the same pressure that the expanding gases exert against the base

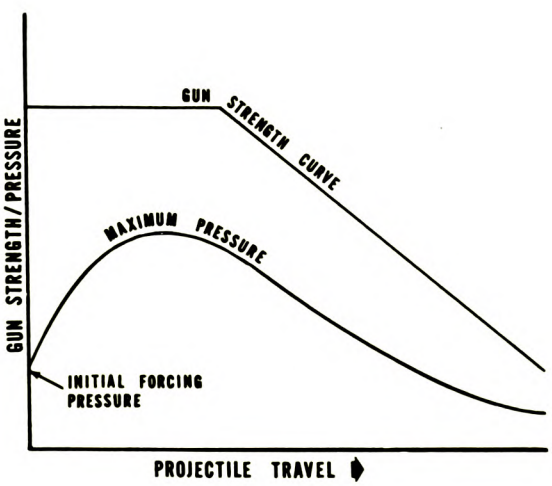

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Figure 4F2.—Typical gun strength and pressure curves.

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of the projectile is exerted equally against all interior surfaces of the gun behind the projectile. Hence the breech part of the barrel must be designed for the maximum stress to be imposed.

After the projectile passes the point of maximum pressure, it continues to be accelerated by gas pressure until it leaves the muzzle. The total area under the curve, up to the point where the projectile leaves the gun, is a rough measure of initial velocity, and the pressure remaining at the muzzle is an indication of the muzzle loss. A high muzzle pressure increases muzzle flash.

4F4. CHANGES IN "CONDITIONS OF LOADING"

By "conditions of loading" are meant the powder used, the weight of charge, the density of loading, the volume and form of the powder chamber, and the weight of the projectile.

a. Powder used and weight of charge. Powders are termed quick and slow in reference to their rate of combustion in a particular gun. For instance, a small-grain powder is quicker than a larger grain of the same shape, since all the grains would be consumed in a shorter time. Not only will the larger grain increase the time required for burning the charge, but it will also cause maximum pressure to be lower and to be reached later in the travel of the projectile. The gun pressure curves shown in figure 4F3 compare slow powders and quick powders where the same weight of charge was used.

Within limits, the muzzle velocity for a particular gun may be increased without causing excessive pressure by increasing the size of the charge and at the same time using a powder that burns more slowly. See figure 4F4.

b. Density of loading. Density of loading is the ratio of the weight of the charge of powder to that of the volume of water which, at standard temperature, would fill the powder chamber. It is a measure of the amount of space in which the gases of combustion may expand before the projectile begins to move.

A high density of loading leaves but little space for initial expansion; consequently pressure builds up rapidly. The maximum pressure behind the projectile is reached early in the projectile's movement through the bore. With lower density of loading, more expansion of the gases may take place before the projectile starts to move. The maximum pressure is achieved later, and this maximum is lower than that with high density of loading. (Compare the curves in figure 4F5.) Other factors remaining equal, increased density of loading increases maximum pressure, muzzle velocity, and muzzle loss.

The densities of loading at present vary between 0.4 and 0.7, depending on the caliber of the gun and on whether the charge is case, stacked bag, or unstacked bag. Since the specific

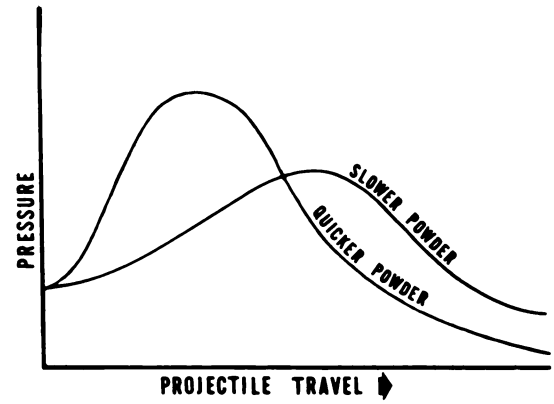

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Figure 4F3.—Typical gun pressure curves showing variations due to quickness of powder, same weight of charge.

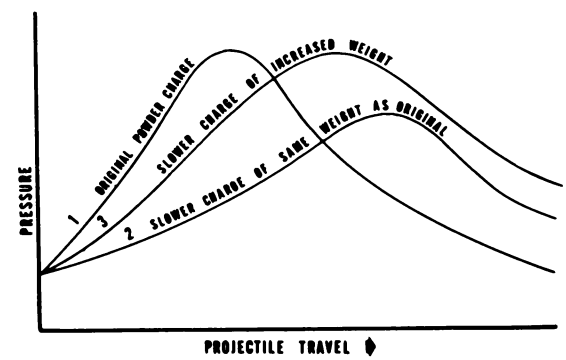

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Figure 4F4.—Typical gun pressure curves showing methods of obtaining increased muzzle velocity in a gun without increasing maximum pressure.

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gravity of smokeless powder is about 1.6, the following relationship holds:

Density of loading = 1.6v,

where

v = the proportion of the total chamber volume which is filled by the charge.

Hence it is apparent that a loading density of 0.4 would require a charge filling 25 percent of the chamber volume, and a loading density of 0.7 would require a charge filling 45 percent of the chamber volume.

When the density of loading drops markedly below the above figures, irregularities of muzzle velocity may be expected. The pressure builds up irregularly instead of smoothly, and the high point may be reached at the wrong time.

A practical example of the importance of loading density would be a projectile lodged part-way down the bore of a gun, greatly increasing the effective chamber volume. Besides greatly lowering density, and causing pressure waves which may build up beyond a safe limit, it extends the area of maximum pressure beyond the area of maximum barrel thickness. A normal powder charge used to dislodge a projectile so positioned might cause the gun to burst, or at least bulge, immediately behind the projectile.

Very high density of loading, on the other hand, may cause detonation of the propelling charge, again resulting in a burst gun.

c. Volume and form of powder chamber. The designers of the gun, having established first the desired muzzle velocity, then the limiting maximum pressure allowable in the gun (determined from study of gun construction), can proceed to determine the volume and form of the powder chamber and the weight of the charge. In a particular gun, the volume and form of the powder chamber change only because of erosion at the origin of rifling and improper seating of the projectile, causing irregular muzzle velocity.

Projectiles differing in weight—for example, high-capacity and armor-piercing types—can be fired from a given gun. High-capacity projectiles, being lighter, will have a slightly higher muzzle velocity.

4F5. SUMMARY OF INTERIOR BALLISTICS DISCUSSION

There is much more to interior ballistics than has been taken up in this section, but you have read enough here to grasp the general nature of this branch of gunnery. Here are repeated the main points of the discussion, by way of summary:

1. Using the same weight of charge, a slow powder produces a smaller maximum pressure than a fast powder, and attains this maximum pressure later in the travel of the projectile.

2. Increasing the weight of a charge of powder of a given grain size increases the maximum pressure attained and causes this maximum to occur earlier in the travel of the projectile.

3. Because of muzzle loss and irregularity of muzzle velocity, slow powders are less efficient than fast powders.

4. The muzzle velocity of a given gun may be increased within limits by using larger charges of slower propellants.

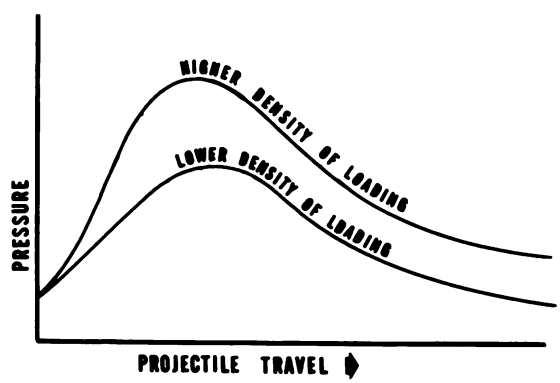

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Figure 4F5.—Typical gun pressure curves showing variations due to density of loading.

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CHAPTER 5

GUN WEAPON SYSTEMS

A. Gun Weapon Systems in General

5A1. GUNS AND THE WEAPON SYSTEM CONCEPT

You already know, from reading earlier chapters in this course, that guns were in use hundreds of years before the weapon system concept was dreamed of. Guns were with only minor exceptions THE weapon (in various shapes and sizes) for all naval warfare until almost the beginning of the 20th century. As guns improved in accuracy, rate of fire, and range, the rough-and-ready methods that had hitherto sufficed for placing gun projectiles with maximum effect were refined until modern techniques and equipment for fire control were developed. As submarines and aircraft added more weapons to the naval arsenal, as well as new varieties of targets for the weapons to engage, the gun lost its primacy as the principal naval weapon and became what it is today—one of the several major classes of weapons, each with its characteristic range of applications and types.

The weapon system concept as applied to guns and their associated equipment differs somewhat from its application to such newer weapon systems as guided missiles and their associated equipment. Missile systems are characteristically integrated—they are conceived, engineered, and designed as systems. Although gun weapon systems function effectively as systems, they are more flexible and less integrated. Thus, a given fire control system may function equally well with any of several types of gun mount, or a gun mount may continue to function with an alternate fire control system or even with only the sights in the gun mount if its normally used fire control system is knocked out.

5A2. ELEMENTS OF A GUN WEAPON SYSTEM

Functionally a gun weapon system includes the following elements:

1. A fire control system.
2. One or more gun mounts organized as a BATTERY.
3. Ammunition supply arrangements.

Since it is inherently flexible both in function and in the equipment that goes to make it up, a gun weapon system is not invariably composed of the same elements—in fact, a combination of the elements that make up a system may vary during a single exercise or battle action. However, a given combination is generally recognized as best—this is the PRIMARY arrangement—and others (SECONDARY arrangements) may be substituted if required by battle casualties or for training purposes. This chapter will concentrate on the preferred combinations that make up the primary systems.

Today all but a relatively few gun weapon systems are either primarily designed for action against air targets (these are antiaircraft or AA systems), or are equally well adapted for engaging air or surface targets (these are dual purpose or DP systems). A few systems designed primarily to engage surface targets can be adapted for certain antiaircraft applications, but these will not be the focus of attention in this book. This chapter is mainly concerned with a typical dual-purpose and a typical antiaircraft gun weapon system.

5A3. GUN BATTERIES

The guns on any naval vessel are organized into groups or batteries, each consisting of

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several gun mounts of similar size and ballistic characteristics. This simplifies the control of gunfire, the supply of ammunition, and the maintenance problem. The size and number of guns in a battery depends on the type of ship.

There are several ways to classify gun batteries on board ship. The simplest is to use the bore diameter (caliber) and the number of calibers as we have done in article 4D5. In practice, the number of calibers is very often omitted in the ship's battery designations, at least when referred to by members of the crew. Thus, a battery of 6"/47 caliber turrets is a 6" battery, and so on. The length of bore in a 5" battery is also dropped from the designation because a ship will have either a 5"/38 or a 5"/54 battery, but not both. Keep in mind that these shortened terms are valid only within your ship or for ships with the same armament. The batteries must be accurately identified in other circumstances. The 5"/54 (Mk 42) and the 3"/50 (RF), described in article 5G3 and section 5E, respectively, must be further identified within their caliber because of the operating differences between these and the older 5"/54 and 3"/50 mounts. A few cruisers have rapid-fire 6" and 8" turrets which require more identification since they differ from their slow-fire prototypes. Most of the rapid-fire turrets are in the Reserve Fleet. As 40-mm and 20-mm guns are not described in terms of their number of calibers; they are designated by bore diameter only.

Batteries are also classified as main, secondary, and machinegun batteries, depending on the type of ship they are mounted on. Traditionally, the largest caliber of guns on board is the main battery; the next largest, the secondary battery; and the remaining installed guns are either heavy or light machinegun batteries. Thus, a 5" battery is the main battery of a destroyer, but only the secondary battery of a cruiser. This method of classifying becomes further complicated when ships sometimes extend the term "main battery" to mean the weapon of greatest potential effect; for example, the planes of an aircraft carrier, or the torpedoes of a submarine. The terms "main armament" and "secondary armament" are used extensively in call-for-fire gunfire support missions.

The last (and probably the best) method classifies batteries according to their service application as follows:

1. SURFACE BATTERY. A battery that is designed primarily to combat surface targets (including shore-bombardment or gunfire support). This battery, sometimes called single purpose, is comprised of 6" or 8" turrets, which are mounted on cruisers. (Turrets can be used against air targets, but this is not their primary application.)

2. DUAL PURPOSE BATTERY. A battery that is designed to combat both air and surface targets (including gunfire support). Dual purpose batteries are 5" guns only. Dual purpose relates not so much to the 5" gun's versatility, as it does to the dual-computing devices and methods in the fire control system.

3. AA BATTERY. A battery that is designed primarily to combat air targets. This battery normally has 3" guns. The 3" gun can also be used against surface targets, and for "direct fire" missions in gunfire support.

B. Fire Control in Gun Weapon Systems

5B1. THE FIRE CONTROL PROBLEM: INTRODUCTION

In any weapon system the fire control problem is essentially that of getting the weapon or projectile to hit the target and explode, or at least to explode when the target and weapon or projectile approach close enough for maximum damaging effect. In gun weapon systems the problem is to lay (aim) the gun in such a way that the projectile will hit or approach close to the target. In some other types of weapon systems the weapon is self-propelled and contains guidance equipment so that it is capable of homing on the target (i.e., it can detect the target and follow it, ultimately catching up with it), or other guidance methods may be available. This is not true of gun weapon systems. Once the projectile has left the gun muzzle, nothing further can be done to affect its course. The gun's fire control problem ideally must be solved before the gun fires.

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In this section we shall take up first the variables in the fire control problem, then the elements of fire control systems, and finally the process by which these elements are used in solving the fire control problem.

Variables in the gun fire control problem. To solve the gun fire control problem, it is necessary to deal with three main types of variables—

1. Exterior ballistics.
2. Target position and relative motion of target and own ship.
3. Inherent corrections necessitated by the physical characteristics of the weapon system.

Each of these is discussed in a separate article below.

5B2. THE FIRE CONTROL PROBLEM: BALLISTICS

From the instant it leaves the gun muzzle until it ends its flight by impact or explosion, the gun projectile's path or trajectory is affected by the following factors:

1. MOMENTUM. As you remember from Newton's laws of motion, any material object has inertia, and, if moving, tends to continue its motion at constant velocity (i.e., at constant speed in a straight line). The important values in determining the momentum of a projectile are its I.V. (initial velocity) and its mass. I.V. is measured in feet per second (usually abbreviated fs) as the projectile leaves the gun muzzle. Mass is conventionally measured in pounds (a convenient measure, if not strictly correct scientifically). If no other factors affected its motion, any gun projectile would have a straight-line trajectory. Note also that all naval guns (except a few special purpose devices) are designed to make the projectile spin at high speed on its long axis. This makes the long axis of the projectile tend to maintain a fixed attitude in space while in flight.

2. GRAVITY. On the earth's surface (and this effect varies only very slightly in different localities and at different altitudes up to several miles) all material objects are subject to the earth's gravitational attraction, which pulls them toward the earth's center. Any unsupported object therefore tends to fall at a constant acceleration of about 32 feet per second per second. Gun projectiles are unsupported once they leave the gun's muzzle; unlike aircraft, they are not airborne, and unlike rockets, they are not supported by propellent thrust. They therefore fall with the same acceleration as if they had been dropped, not fired. The idea may be novel to the student, but the fact is that a projectile fired from a horizontally aimed gun will strike the surface of the sea at the same instant as a similar projectile that has merely been dropped from the same height above the water. It is, of course, true that the fired projectile will hit the water some distance away. (Part A, fig. 5B1.)

Under the influence of momentum and gravity (but of no other factors) the trajectory of a projectile will be one of a family of symmetrical curves called parabolas. For a given I.V. and projectile mass, the projectile will then travel farthest from the gun if the gun barrel is elevated to make a 45° angle with the horizontal. (Part B, fig. 5B1.)

3. AIR RESISTANCE. As figure 5B2 (based on an instantaneous wind-tunnel photograph) shows, a projectile traveling at a speed of up to 3,000 feet per second creates a considerable disturbance in the air. At such speeds, air at sea-level density is far from insubstantial, and its resistance significantly slows the projectile throughout its flight. Air resistance affects the trajectories of all projectiles, but its effects, which depend on air density, are much greater on less massive ones.

The trajectory as affected by momentum, gravity, and air resistance is still more or less parabolic, but is not symmetrical; the projectile is traveling slower as it approaches the end of the trajectory, and (fig. 5B3) it falls at a larger angle with the horizontal (tending toward 90°).

4. WIND. Wind is air movement. Movement of the air with respect to the earth is called true wind. Air movement caused by the motion of a ship is called relative wind for that ship. Apparent wind is the vectorial sum of these two winds, and it is the quantity read from the ship's anemometer. Wind speed is measured in knots, and wind direction in degrees from the reference (true north, or ship's bow) clockwise to the direction FROM which the wind is blowing. By vectorial analysis, apparent wind can be resolved into relative wind and true wind. True wind is the wind input to fire control computers. True north is the reference for true wind, thus true wind is independent of ship's movement; however, both relative wind and apparent wind depend on own ship's course and speed.

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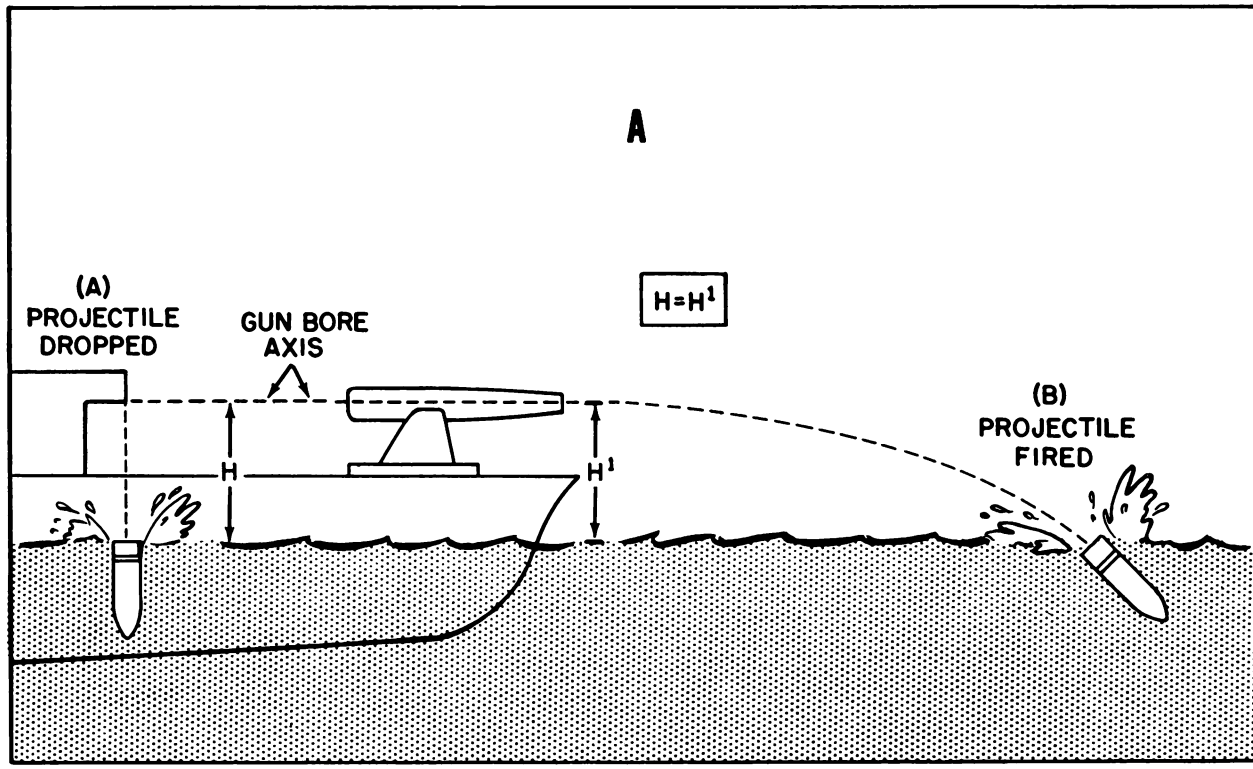

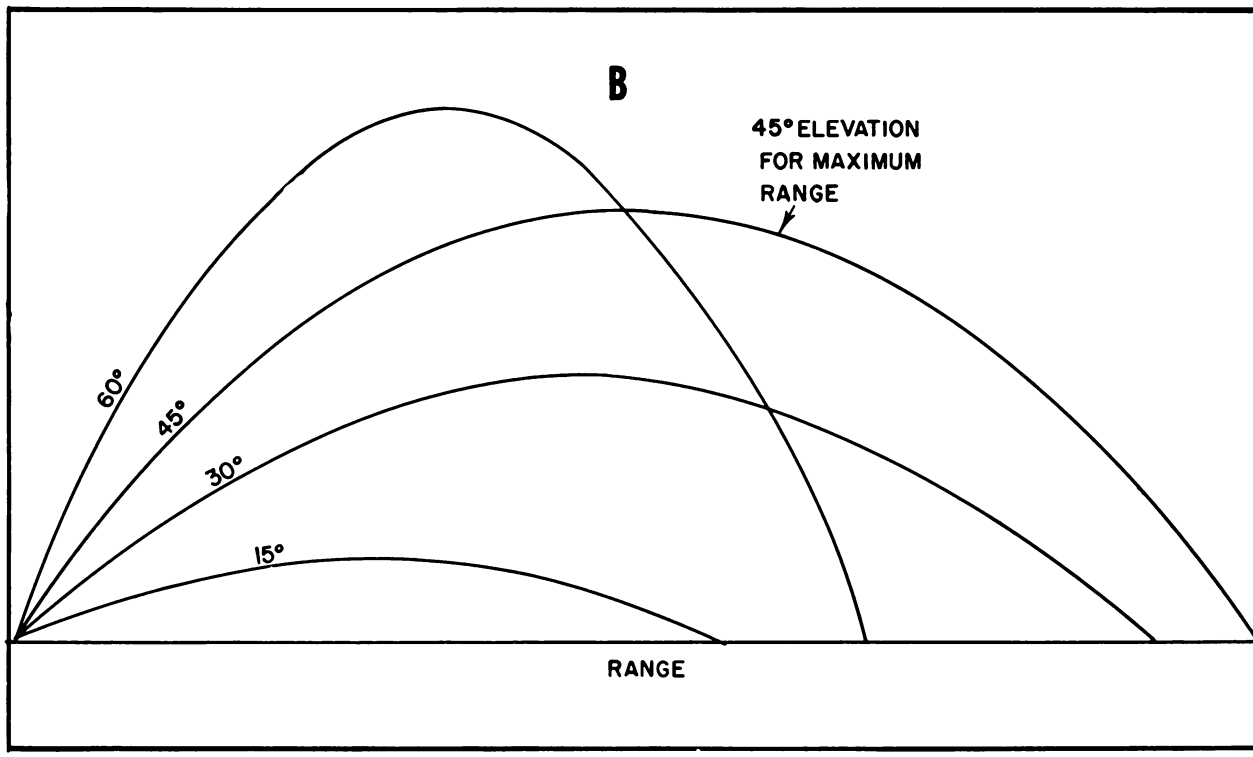

Figure 5B1.—Projectile trajectory as affected by gravity. A. Projectile (B) fired from horizontally aimed gun strikes water surface at same instant as projectile (A) dropped from same height. (Height H=height H'.) B. Theoretical parabolic trajectories in vacuum at various gun elevations.

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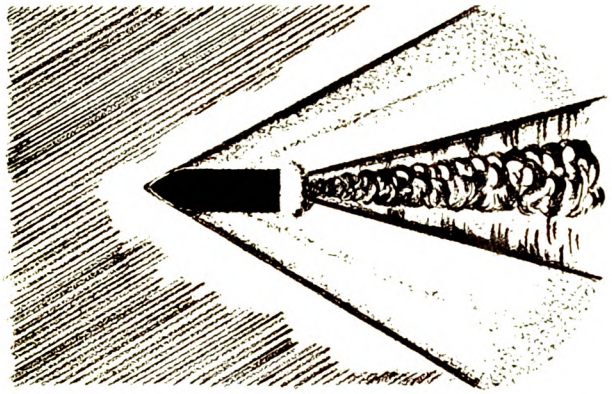

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Figure 5B2.—Portrait of a projectile in flight.

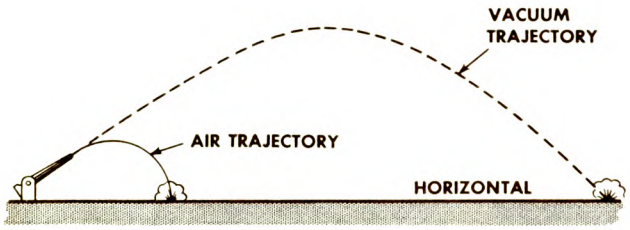

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Figure 5B3.—Comparison of vacuum and air trajectories.

In fire control computers, true wind is resolved into two components with respect to the line of fire. One, called range wind, lies in the line of fire and may either accelerate or decelerate a projectile. Cross wind is the other component; it blows at right angles to the line of fire moving the projectile to the left or right of its planned trajectory. These components and their effects are automatically computed, and automatic corrections are made to the gun's position in train and elevation.

A ship's anemometer measures surface wind, but a projectile's trajectory passes through various altitudes. These altitudes, primarily because of air density and temperature, have diferent wind velocities than those on the earth's surface. A ship's meteorologist can track the flight of a balloon and measure the velocities and directions of tropospheric winds. Or, periodic wind reports are often received by radio from a shore station which has better wind measuring facilities. Most ships do not have a meteorologist on board; they will have to depend on reports from other ships or stations.

The Aerological Ballistics Manual, NavWeps 50-1P-528, provides charts, graphs, and methods for computing a BALLISTIC WIND. Ballistic wind is the resultant wind vector from zero altitude to about 20,000 feet. But if the projectile's maximum ordinate is less than 20,000 feet, only the wind affecting the projectile is considered in the ballistic wind computation. Wind velocities and directions are measured in 2500-foot increments (layers) from the surface horizontal to 20,000 feet. Weighted factors are provided in the manual so that any number of increments can be used easily and quickly. The number, of course, depends on the projectile's maximum ordinate. All necessary data for air and surface targets, including various altitudes and ranges, and various guns used, are provided in the manual. The final ballistic wind calculation for a particular type of engagement, at a specified altitude and range, is substituted for true surface wind in the fire control computer. In the absence of ballistic wind data, true wind (surface) is the computer input.

5. DRIFT. Drift (fig. 5B4) is a deflection of the trajectory to the right, and is caused by the interaction of gravity, air resistance, and the projectile's clockwise spin. (Counterclockwise spin would deflect the trajectory to the left, but all naval guns except the .45 caliber have clockwise rifling.) Drift is directly proportional to range. It is independent of wind.

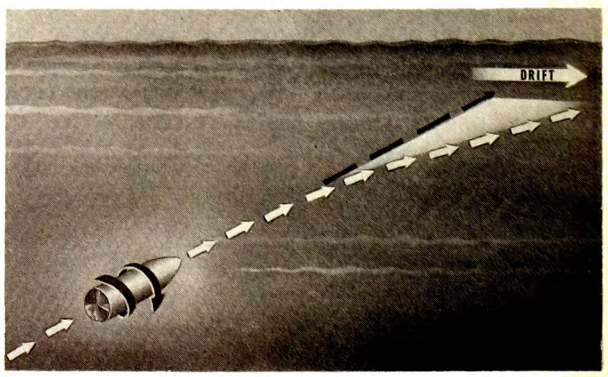

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Figure 5B4.—Clockwise projectile spin causes drift to the right.

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6. EARTH'S ROTATION AND CURVATURE. The discussion so far has implicitly assumed that the earth is flat and does not rotate. For ranges up to 20,000 yards or so, such an assumption does not cause any serious errors in fire control. At extreme gun ranges (30,000 yards and more) these two factors become important enough to be taken into account, particularly in firing at surface targets. Since such ranges are characteristic of the surface batteries of heavy cruisers (of which there are only a few in the active fleet) and those of battleships (none of which are in the active fleet), we can neglect these effects in this course.

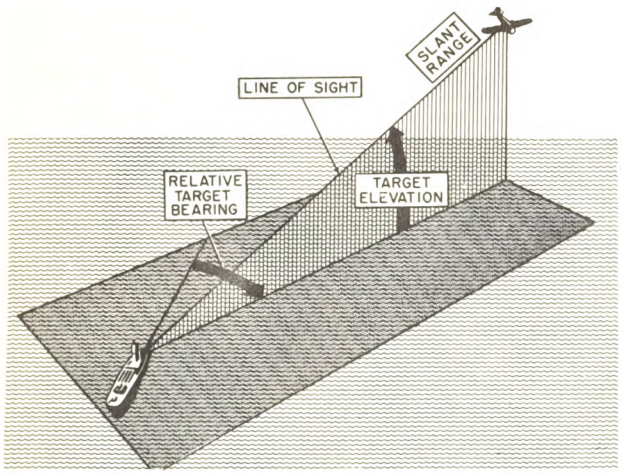

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Figure 5B5.—Relative target bearing, slant range, and target elevation.

5B3. THE FIRE CONTROL PROBLEM: TARGET POSITION AND RELATIVE MOTION OF TARGET AND OWN SHIP

In the fire control problem, target position at any instant is measured in terms of target bearing (a horizontal angle measured from a vertical reference plane), target elevation (a vertical angle measured from a horizontal reference plane), and range (a linear distance measured along the line of sight (LOS) to the target (fig. 5B5)).

As you noted at several points in connection with the discussion of exterior ballistics, the effect of the factors listed in the preceding article depends on, among other things, range.

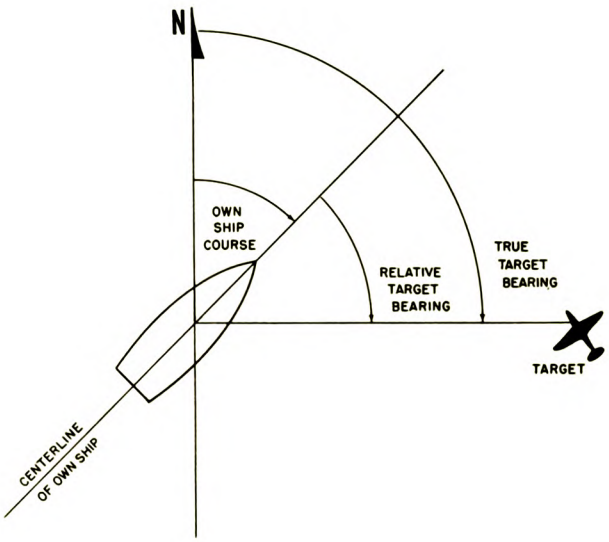

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Figure 5B6.—Relationship between true bearing, relative bearing, and own ship course.

Another way of putting it is to say that they depend on time of flight—i.e., the time lapse between the projectile's departure from the gun muzzle and its impact or explosion. During this time the factors that determine the projectile's trajectory have their effect; obviously, the longer the time of flight, the greater their effect. Since, other things being equal, at any specified I.V. time of flight is proportional to range. This is one reason that it is important to know the range to target (generally measured in yards) as accurately as possible. Range to an air target, as measured along the LOS, is called slant range to distinguish it from range measured on the surface.

There are two kinds of target bearing. Relative target bearing is the angle, measured clockwise in degrees and minutes, between a vertical plane through the centerline of own ship and the line of sight (LOS) to target. (This is illustrated in fig. 5B5.) True target bearing is measured similarly, but from a vertical plane containing a line to true north. Figure 5B6 shows the distinction and relationship between true and relative bearing, and demonstrates that true bearing is the algebraic sum of own ship course and relative bearing.

For the location of an air target with respect to own ship, one more value is needed—target elevation (generally measured in minutes of arc from the surface horizontal plane.)

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If now we were to assume that the target and own ship were stationary with respect to each other, it would be necessary to correct only for exterior ballistic factors and the gun would be laid for a hit on the target. However, such a situation is rare. Target movement with respect to own ship is a part of every practical fire control problem, and it becomes increasingly important as ranges decrease and target velocities increase. (You can expect some air targets to be moving at over 600 knots.) In fact, at very close ranges (in the neighborhood of 2,000 yards or less) the ballistic factors are completely overshadowed in importance by corrections for target velocity, and many of the ballistic factors are not even considered in fire control systems designed for close-range work. This is true because at short ranges

(a) time of flight is short.

(b) angular velocities (i.e., changes in target bearing and target elevation) increase as target range decreases, even when target speed as measured in knots remains the same.

(c) time available for arriving at solutions to the fire control problem is so short that there is time only for essential steps in solution.

5B4. THE FIRE CONTROL PROBLEM: INHERENT CORRECTIONS

The miscellaneous factors that we here lump under the label INHERENT CORRECTIONS include corrections for:

1. Motion of the gun platform (i.e., the ship's rolling and pitching motions as it floats on the water).

2. Parallax—i.e., distance between fire control system elements located at different points aboard ship.

3. Divergence of gun mount roller paths from the deck reference plane.

These factors are called "inherent" because they are unavoidable in any system designed, within the limitations of contemporary techniques, to function when installed over most of the length of a warship that spends its lifetime on the surface of the sea.

Corrections for gun platform motion. As you remember, the essence of fire control is to position the gun barrel so that the projectile's trajectory will culminate in its collision with the target. We may (as we did earlier in this chapter) assume for purposes of analysis that the deck on which the gun mount stands is stable, but in practice it is not generally possible to make this assumption. Nor is it practicable to stabilize the deck itself. Instead, either of two alternative correction methods is used. One requires that the gun be continuously repositioned by its power drive so that it maintains the desired attitude regardless of the ship's roll and pitch. The other (much less frequent) is to control the firing circuit so that as the ship rolls and pitches the firing circuit is energized only during those instants when the gun happens to be in the position required for hitting the target.

Two kinds of correction are required for the effects of ship's roll and pitch. One is correction in level and crosslevel (fig. 5B7). (Level angle

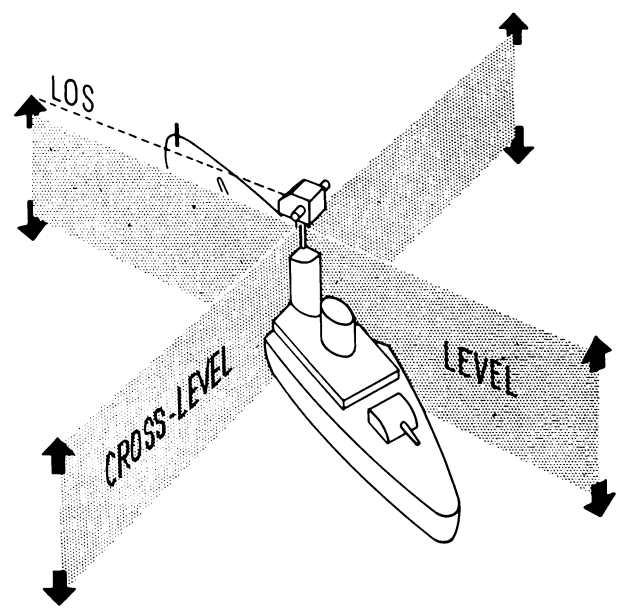

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Figure 5B7.—Level and cross-level.

is the angle that the deck plane, which pitches and rolls with the ship, makes with the horizontal, as measured in a vertical plane containing the LOS. Crosslevel angle is measured at right angles to level angle.) Crosslevel causes trunnion tilt. As the gun mount tilts with the ship's motion, the gun no longer elevates in a plane perpendicular with the horizontal. This introduces errors, both because the gun doesn't elevate to the proper angle, and because elevation in a plane not perpendicular to the horizontal causes it to shift in train. Thus, if the right trunnion is at a chosen instant lower than the

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left, elevating the gun by x number of minutes with respect to the horizontal will require more than x minutes of elevation in its tilted plane, and in addition the barrel after elevation will be displaced to the right of the plane it was in before elevation. Figure 5B8 shows the corrections required to compensate for trunnion tilt.

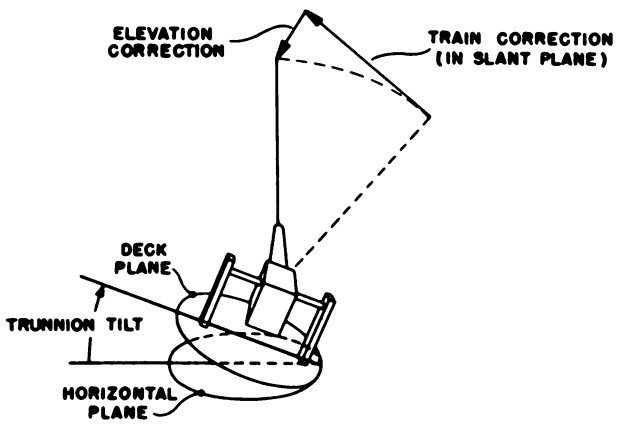

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Figure 5B8.—Corrections for trunnion tilt.

Parallax corrections. In general, parallax is the apparent displacement of an object (for example, a target) as seen from two different locations. The phenomenon occurs in several different contexts in fire control. We are now concerned with the effect diagrammed in figure 5B9. Relative target bearing is different at each

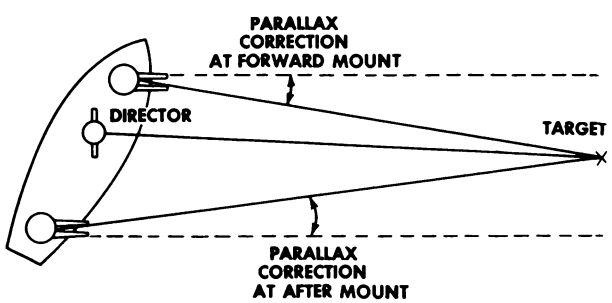

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Figure 5B9.—Horizontal parallax.

gun mount and at the director. The parallax correction compensates for these differences.

Correction for roller path tilt. Ideally, the roller path of each gun mount should be parallel to that of the director used as the reference. Although the tilt of a gun mount with respect to the reference is in modern naval construction always small (rarely over a degree, and usually much less), it must be corrected. Some tilt is unavoidable because a ship's hull is supported much differently in the shipyard than it is when afloat. Individual corrections are required for each gun mount. The correction is made in elevation, but its magnitude depends on the angle to which the mount is trained. Figure 5B10 shows the effect of roller path tilt in exaggerated form.

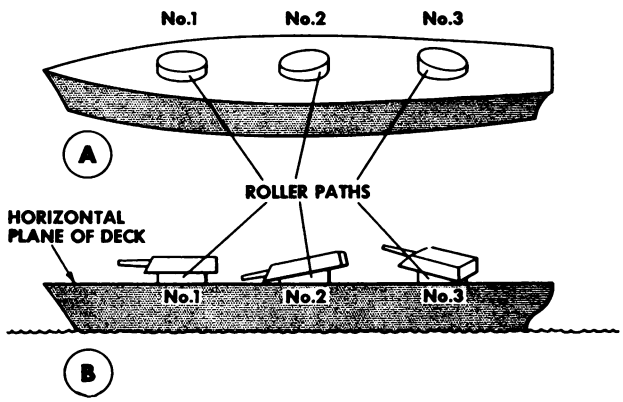

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Figure 5B10.—Effect of roller path inclination (much exaggerated).

5B5. ELEMENTS OF GUN FIRE CONTROL SYSTEMS

As you noted in earlier articles in this section, the complexity of the fire control problem, and hence of the fire control system necessary for its successful solution, increases with the maximum range of the guns associated with the system, since ballistic factors are relatively more important when the time of flight is longer. At the same time, at shorter ranges the position and motion of the target with respect to own ship become relatively more important than the ballistic factors. Moreover, at shorter ranges the time available for solution of the problem is much more limited than at longer ranges. Consequently, instead of a single "universal" fire control system or type of system used in all applications, you find that there are two main types, each best adapted to a particular kind of application. One of these

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is the relative-rate type, which efficiently deals with fast targets at short ranges. The other is the linear-rate type, which is particularly well adapted to deal with the more complex ballistic computations required for distant targets.

Examples of both types will be described in more detail later in this chapter, but so that you may understand better the description below of how the fire control system solves the fire control problem, consider briefly the elements of each type.

Linear-rate systems. Linear-rate systems are used for both surface and air targets at much longer ranges than those for which relative-rate systems are generally used. The system consists of (fig. 5B11) a director located

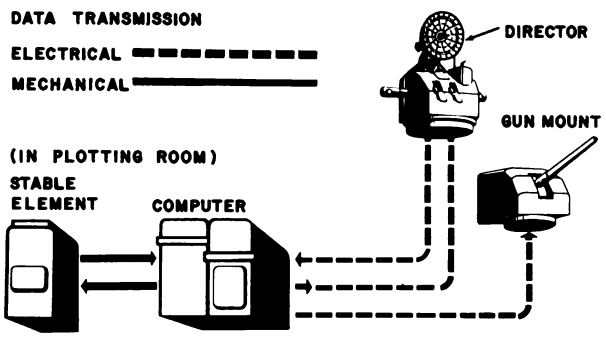

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Figure 5B11.—Elements of a linear-rate gun fire control system aboard a destroyer.

high in the ship's structure, a computer and stable element closely linked to each other and located in a plotting room in the hull, and the gun mounts (commonly the 5-inch battery, though the system can be connected to control other mounts also). All these elements are interconnected by electrical data transmission circuits, except that the stable element usually is mechanically connected to the computer.

The director is equipped with telescopes, optical rangefinder, radar installation, data transmitters and receivers, and power drive, so that it can

a. determine target bearing, elevation, and range either optically or by radar.

b. be power driven by computer-generated signals so that the director crew can verify that the computer is developing the proper fire control solution.

c. "lock on" to the target for automatic radar tracking (i.e., automatically follow the target as its location changes with respect to own ship.)

The computer (depending on the specific system) may be either an electromechanical or an electronic-electromechanical unit. It accepts all ballistic factors (including I.V.) as well as target data and data on own-ship course and speed. It transmits gun position data to the gun mounts it controls. And it can send its fire control solution to the director as electrical signals that position the director optical and radar elements to indicate how accurately it is solving the fire control problem. The computer contains no gyroscopic elements.

The stable element contains a gyroscope which because it remains fixed in attitude generates a stabilized reference plane to which all angular values received and computed can be related.

The data transmission receivers in the gun mounts control the gun power drives so that the guns will be positioned in accordance with the signals transmitted from the computer.

Relative-rate systems. The essential parts of a simple relative-rate fire control system are a director and a transmission system through which the gun position data required for accurate firing are transmitted to the gun mount. In simpler systems, there may be one director for one or two mounts, and the directors are located fairly close to the mounts they control. Range is either estimated optically and cranked in manually, or measured by radar. The director operator looks through the optical sight on the director (or he may use radar) and tracks the target (that is, as it moves in his field of vision he keeps it aligned with his LOS as indicated by a reticule in the sight, or in the center of his radar display). This movement affects a gyroscope and a pendulum device in the director case. Electrical pick-up devices in the director sense the gyro and pendulum movements, and send electrical signals to the gun mounts. The signals correspond to the gun positions required for hitting the target, and they either control the mount power drive so that the guns assume the desired positions, or the gun crews may control gun position manually in accordance with the signals as displayed on dials. Simple relative-rate systems take into account only a few ballistic factors—generally gravity, drift, and air resistance.

In some types of relative-rate systems the director may be divorced from the gyro and

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pendulum devices. The gyro is then a component in a separate computer. The more complex relative-rate systems will accept additional ballistic factor data inputs and are more accurate, particularly at longer ranges, than the simpler systems.

The most elaborate systems utilize power-driven directors rather than the manually operated directors of the simple system described above. Under radar control, these can track targets automatically once they are "locked on." The more complex systems also include an additional gyro for stabilization, like the one described above for linear-rate systems, and additional computers for wind data inputs and for generation of gun positioning signals for two gun batteries simultaneously.

On-mount fire control elements. The important fire control system elements on gun mounts are the data transmission receivers, the power drives, and the sights. (In some systems, radar elements may also be installed on the mounts.) The first two of these have been discussed in chapter 3; we shall briefly concentrate on the sights. These are optical devices, either telescopic or nontelescopic, equipped with crosshairs intersecting at right angles in the center of the view field. Any target as seen through the sight at the center of the view field is on the line of sight (LOS). Sight dials on the mount indicate at all times precisely the angle that the LOS makes with the axis of the gun's bore. In most mounts, dials concentric with the sight dials and driven by data receivers controlled by the computer are automatically positioned to display the angles that the gun bore axis should make with the LOS if the gun is to be laid for hitting the target. A crewman can manually crank the desired angles into the sight-setting indicator (an indicator with gearing which positions the sights). These arrangements permit continuous aiming of the gun even if the gun power drives quit, if the data transmission from the computer is interrupted, or if the computer or other fire control system elements are knocked out.

5B6. SOLVING THE FIRE CONTROL PROBLEM: GENERAL

As you remember from the beginning of this section, the fire control problem consists essentially of three groups of variables. In a given fire control system, some individual variables may either be taken into account or neglected, depending chiefly on target velocity (with respect to own ship) and range, and on desired accuracy and speed of solution. The main steps in solving the fire control problem are:

1. MEASUREMENT of each of the variables to be taken into account.
2. COMPUTATION of what gun position must be in relation to an LOS from own ship to target so that the projectile will hit the target, and transmission of this information to the gun mounts. (This computation and transmission may also include projectile fuze setting if required.)
3. POSITIONING THE GUNS in accordance with this information and energizing firing circuits as required.
4. OBSERVATION of effects of firing and correction of fire control information.

Now consider each of the steps in somewhat more detail.

5B7. SOLVING THE FIRE CONTROL PROBLEM: MEASURING OR ESTABLISHING VALUES OF VARIABLES

Ideally, each variable in the fire control problem should be observed and accurately measured, then entered in the computing system. As a practical matter, some may be estimated and "cranked in" (i.e., put into the system manually), and some may be considered as having a fixed relationship to another variable (for example, the effect of gravity has such a relationship to time of flight), so that they don't have to be measured. (We have already noted that in all but the most refined systems some variables are omitted entirely because they are not considered essential to a solution of practical accuracy.)

1. Ballistic variables are measured and entered into the fire control system computer as I.V. Most of these variables were discussed in chapter 4. For a detailed discussion of how I.V. is determined, see appendix B.
2. Gravity has a fixed relationship to the time of flight, which in turn has a known relationship to range. Its effect is therefore "built into" the computer as a specially shaped cam (in electromechanical computers) or electrical network (in electronic computers).
3. Air resistance is in most medium- and long-range systems determined by fire control personnel who plot observed air temperature and barometric pressure on a nomogram and

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then determine the required correction. (Air density correction nomograms are printed in range tables. A specimen is reproduced in appendix B, which also contains details on how this and several other ballistic corrections are determined.) The correction is put into the computer as part of I.V.

4. Wind is a factor in medium- and long-range systems; it is generally neglected in simple relative-rate systems designed for use at short ranges. In long- and medium-range systems ballistic wind is cranked into the computer.

5. Drift is treated like gravity.

6. Earth's rotation and curvature are figured from range tables and their effects are cranked into the system as direct increments to sight angle and deflection. The computer does not solve for these. In any case, these values are used only against surface targets at extreme ranges. See appendix B for details.

Target position and relative motion of target and own ship are important factors in all gun fire control systems, but for high-speed targets at shorter ranges they dominate the fire control problem.

Target position is fixed by three coordinates—bearing, elevation, and range. All three can be measured optically in a linear rate system. The first two are established when the sight telescopes in the director are on target. Angular values of director train (an angle nearly equal to relative target bearing) and director elevation (an angle measured with respect to the deck plane, vertically to the LOS) are sent to the fire control system computer by data transmitters (synchros). A linear value of range is measured at the rangefinder and also sent by synchro to the computer.

Radar can be used to measure all three coordinates in a Mk 37 linear rate system. Data transmission is generally the same when the director is tracking by radar, except that the range synchro information comes from the radar instead of the rangefinder. The Mk 37 (fig. 5B11) is the principal linear rate director used in the Navy. It can track targets optically in train and elevation while maintaining an automatic radar track in range: this is called partial-radar control. Or, either train or elevation can be shifted into automatic radar track without shifting the other, provided the director is radar-tracking in range.

When the director is in full-radar track, the system, including the computing devices, is fully automatic. Sometimes (particularly at long ranges) the target echo is too small for full radar tracking, but can still be seen on the radarscopes in the director. As long as it can be seen, it can be tracked by radar. The pointer and trainer move their power drive controls to keep the target video aligned (in elevation and train, respectively) to the line of sight references on the radarscopes. These references correspond to the actual position of the director in elevation and train, and are aligned to the crosshairs in the optical sights. The radar range operator keeps the target video manually "gated" or aligned to the range measuring device on his radarscope, i.e., the notch, mark, or step as the case may be.

There are many different types of relative-rate directors used in the Navy today. Some can track automatically by radar, others track manually by radar, and still others use a combination of radar and optical tracking. And then there were optical relative-rate directors which were installed before radar was used in fire control; these use estimated ranges. One common feature that all relative-rate directors have is that they use gyros to measure angular tracking rates. More about this later.

In the simplest relative-rate systems the director operator tends to keep the director stabilized as he tracks the target; in any case stabilization errors in such systems are not important at close ranges with high-speed targets. In longer range relative-rate systems and in all linear-rate systems the system outputs compensate for ship's roll and pitch because they are developed with respect to a stabilized reference plane, which is kept horizontal by a gyroscope. In relative-rate systems the stabilization gyro is incorporated into one of the consoles or into the director of the system; in linear-rate systems the gyro is in a separate console called the stable element or stable vertical. An alternate manual stabilization arrangement used in emergency in some linear-rate systems requires that a crewman sight at the horizon continuously through a telescope coupled to the remainder of the system by a synchro whose output provides the stabilization signal.

Parallax correction is important only in more elaborate systems, in which some of the gun mounts being controlled are located at some distance from the director. A special section of the computer develops parallax correction for a base length (i.e., the distance

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between director and gun mount) of 100 yards. This is called the unit parallax correction. For this or any other base length, the closer the target the greater the angular correction needed for parallax. However, the base length assumed for the unit parallax correction is not likely to be correct for any one gun mount, since obviously the parallax correction ought to be greater for mounts further from the director than 100 yards, and less for mounts that are closer. Consequently, there is in each gun mount a set of change gears which converts the unit correction to the correction required, based on the ratio between the assumed base length and the actual base length. Parallax is also computed to compensate for vertical distance between mounts and director, but since all mounts are more or less equally far below the directors, the computed correction is fed equally to all.

Roller path tilt correction is performed mechanically by a device built into each gun mount. The computer in the fire control system has nothing to do with this correction, which is different for each mount. Chapter 9 illustrates one type of roller path tilt corrector, and briefly describes how it is used.

5B8. SOLVING THE FIRE CONTROL PROBLEM: COMPUTATION AND DATA TRANSMISSION

This course does not go deeply into the mathematics of the fire control problem and its solution. The details of functioning of a fire control computer will therefore not be described. However, in chapter 3 you learned that such mechanisms as gears, cams, and differentials can be used to perform all the basic arithmetical operations as well as many trigonometric ones. Chapter 3 also described other mechanisms used in a typical fire control computer, such as the integrator, component solver, multiplier, etc. These enable the electromechanical computer, for example, to perform all the mathematical functions necessary in solving the fire control problem.

There are basically three different varieties of computer used in present day Navy gun fire control systems—the GYROSCOPIC, the ELECTROMECHANICAL, and the ELECTRONIC. All three are what computer engineers call analog computers, as distinct from the more famous (because of their applications in science and the business world) digital computers, such as UNIVAC, ENIAC, NORC, and SEAC. You can get some notion of the distinction betweeen digital and analog computers by comparing two methods of adding. Suppose you want to add 5 and 3. If you put down five strokes (/////) and three strokes (///) and count them all, you have a total of 8. This is a digital operation (and you can make it a real digital operation by doing it on your fingers). Now, as an alternative method, suppose you draw a line 5 inches long, and add to one end of it another line 3 inches long. The total would then be 8 inches long, and this method is analog computation. The difference from digital computation is that you don't use separate, discrete integers or digits; you use linear (or angular) quantities. There are advantages to each method of computation. Analog computers aren't as versatile as the digital type, but in the present state of the art it's easier to get faster solutions for specified types of problem (such as the fire control problem) from analog computers than from digital.

GYROSCOPIC COMPUTERS are used in relative-rate systems. They may be housed in gunsight cases which are mounted on directors, or they may be in the director itself. Their function is to generate the correct lead angles, and lead angles (for bearing and elevation) depend on two variables in addition to ballistic corrections. The variables are: (1) the angular velocity of the director or gunsight in bearing and elevation, and (2) the time-of-flight (or range) to the target.

A gyroscopic computer uses a rate-of-turn gyro as shown in part A of figure 5B12. Assume that the gimbal frame in part A is attached to a gunsight case, and in part B is made to revolve rapidly by a motion of the gunsight case while tracking a target. Notice that the gyro precesses in part B, and that it is restrained by two springs. The tension of these springs is set (either manually or by radar) to be proportional to the target's range. The amount of precession of the gyro, then, is proportional to the angular velocity of the case and the range to the target. As range increases, the tension on the springs decreases. By this action a larger lead angle is developed at longer ranges for a given angular velocity. The springs have another function in that they return the gyro to zero precession when tracking has ceased, and they supply the force to compensate for decreases in angular velocity while tracking.

There are two basic ways to use the rate-of-turn gyro's precession in the fire control

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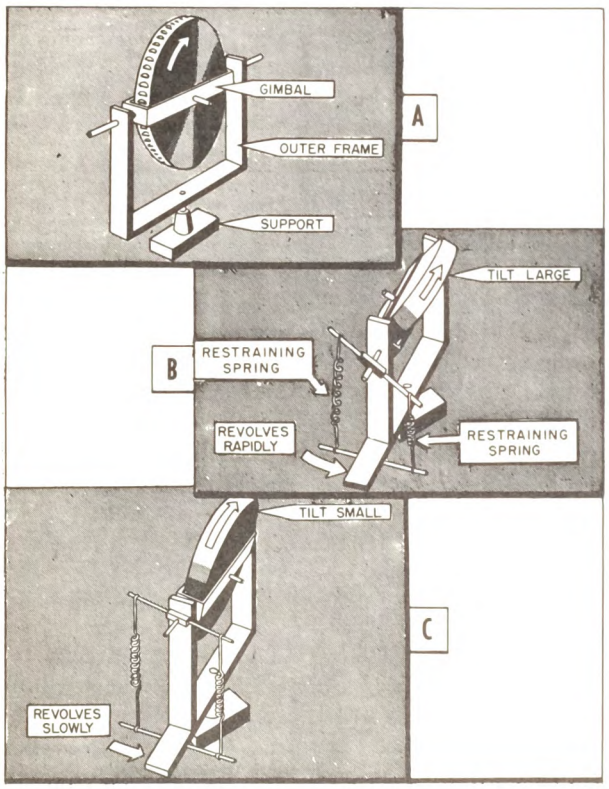

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Figure 5B12.—Functioning of rate-of-turn gyro (simplified). A. Gyro elements. B. Action in tracking fast. C. Action in tracking slowly.

system. Older systems use the gyro to control the optical train of the gunsight. The gunsight operator's line of sight is controlled by connecting gyro precession to prisms within the optical train. Since the guns are aligned to the sight case, offsetting the line of sight within the case introduces the lead angle into the system. The other way to use these data starts is with electrical sensors, called pickoff units. A pickoff unit senses the gyro displacement without perceptibly disturbing it, and produces a proportionate electrical signal. Electrical signals, proportional to lead angles, are sent to the fire control system computer where orders for the guns are computed in some systems. They may also be a direct input to the gun in other systems.

There are various rate-gyro devices in fire control which use one or more gyros. Some use electromagnetic damping devices instead of restraining springs. And some use ballistic gyro weights, while others use torque motors for the ballistic corrections. Discussing all of them in this text would obscure, rather than clarify, the basic theory.

ELECTROMECHANICAL COMPUTERS. To solve the fire control problem for a moving target, the fire control system must have the rate of target movement with respect to own ship—specifically, the rate of change of target bearing, target elevation, and range. Since own ship is usually in motion also, its motion must be entered into the computer. Own ship's course is transmitted from the ship's gyrocompass, and own ship's speed is transmitted from the pitometer log. Both are synchro-transmitted inputs to the computer. Rates of change in bearing, elevation, and range go into the fire control computer as the director tracks the target. The computer solves the problem by performing a series of mathematical operations with the data put into it. The operations are performed almost entirely by mechanical units of the type described in chapter three. The input data are invariably in the form of shaft rotations or other mechanical displacement. The mechanical displacement any be produced either by manually setting a knob or crank, or through a servomotor (which reproduces relatively weak servoinputs which may be either electrical or mechanical), or a synchro receiver (which reproduces an electrical input without amplification). The computer outputs are always mechanical, but are translated into electrical synchro signals (with one exception) to go to other system components. They are also displayed on dials and other indicators.

In some fire control electromechanical computation equipment, simple computation (addition and subtraction) may be performed by synchro units.

ELECTRONIC COMPUTERS. Electronic analog fire control computers use specific circuits or electrical elements to perform specific mathematical functions. For example, two voltages can be added or subtracted in an electrical network (depending on their polarity); if a-c voltages are used, changing their phase relationship yields a voltage that represents the vectorial sum of the voltages. Transformers, both fixed and variable, can be used for multiplication or division—changing the transformer turns ratio changes the divisor. Rotary variable resistors called potentiometers can vary the amount of resistance in a circuit either in straight-line fashion or in accordance with a selected nonlinear function (for example, the

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effect of drift). Such functions can also be calculated by using special nonlinear amplifier circuits. Small rotary transformers called resolvers can either resolve an a-c voltage representing a vector quantity into its components (for example, yield north-south and east-west components of own ship course and speed), or add the components to yield a solution expressed in an a-c voltage of specific amplitude and phase, or perform other functions with vectors. The shafts of such rotary devices as potentiometers and resolvers (as well as synchros) are in such electronic computers usually driven by servomotors energized by servoamplifiers. An electronic analog computer can thus be functionally substituted for an electromechanical computer.

Data transmission. Except for mechanical connections between computer and the stable element in some linear-rate systems, all data transmission between fire control system elements is through synchro systems. These were explained in principle in chapter 3. All inputs and outputs between systems are translated into synchro signals of transmission and retranslated into suitable electrical and mechanical outputs at the receiving end.

Thus, for example, the signal voltage developed by a pickoff unit on a train rate-of-turn gyro in a relative-rate director controls a servo whose motor drives a synchro transmitter. The transmitter's output goes through synchro wiring to the gun mounts.

The data transmitted electrically by synchro to the gun mounts from the fire control system include at the minimum, gun train and elevation orders. In some relative-rate systems no other data are transmitted; in others, and in linear-rate systems, transmitted data may include sight angle, sight deflection, fuze-setting order, and parallax.

5B9. POSITIONING AND FIRING THE GUN

With the fire control problem's variables evaluated and the solution available, it is possible to lay the gun so that the projectile will hit the target. Other requirements may limit the solution in such a way that firing can successfully take place only at certain instances, in which case the solution must specify those instants.

Making Up Gun Orders. The process of gun-laying is essentially that of offsetting the axis of the gun bore from the LOS by a specific angle. This compensates for the divergence of the trajectory from the straight line it ideally would be in interstellar space with stationary gun and target. No matter what any specific variable in the gun fire control problem may be, or what its magnitude and direction are, the only possible ways of compensating for it are (a) variation in the propelling charge or projectile (which for all practical purposes is so infrequently done that we can neglect it here) or (b) algebraically adding an increment in the angular offset between gun bore axis and LOS (the only method we consider in this chapter). Since the gun is positioned in two perpendicular planes by its train and elevation mechanisms, the offset is always measured in two perpendicular planes.

Figure 5B13 shows the angular offsets for a surface target. The vertical offset in part A is called SIGHT ANGLE; the deflection offset in part B, SIGHT DEFLECTION. These two angles are equal to the total lead angles for elevation and bearing in both air and surface exercises. In a surface exercise, the elevation lead angle assumes the properties of a "range lead angle" since range is a function of the gun's angle of elevation. Smaller angular values make up sight angle and sight deflection. For example, drift is part of sight deflection, and an angle called SUPERELEVATION is part of sight angle. Superelevation is the angle that the gun must be elevated above the line of sight to compensate for the downward pull of gravity. It is not affected by the relative motion of own ship and target; but it is affected by range and elevation, the variables which cause changes in trajectory. Thus the required superelevation, at any given range, is determined by the uncorrected trajectory. If own ship and target in part A of the figure are stationary, and if wind effects are discounted, then superelevation will equal sight angle.

Figure 5B14 shows the vertical offset for an incoming air target. Notice that the LOS to target is elevated above the horizontal by an angle labeled target elevation. The gun barrel is elevated above the LOS by sight angle. Sight angle here not only includes a correction for superelevation, but predictions based on relative motion as well.

The angles which ultimately position the gun are called GUN ELEVATION ORDER and GUN TRAIN ORDER. Essentially, each contains an angle equal to target position in elevation and bearing, respectively, plus the computed lead angle for each. Since a gun elevates and trains in the ship's deck plane, gun elevation order is

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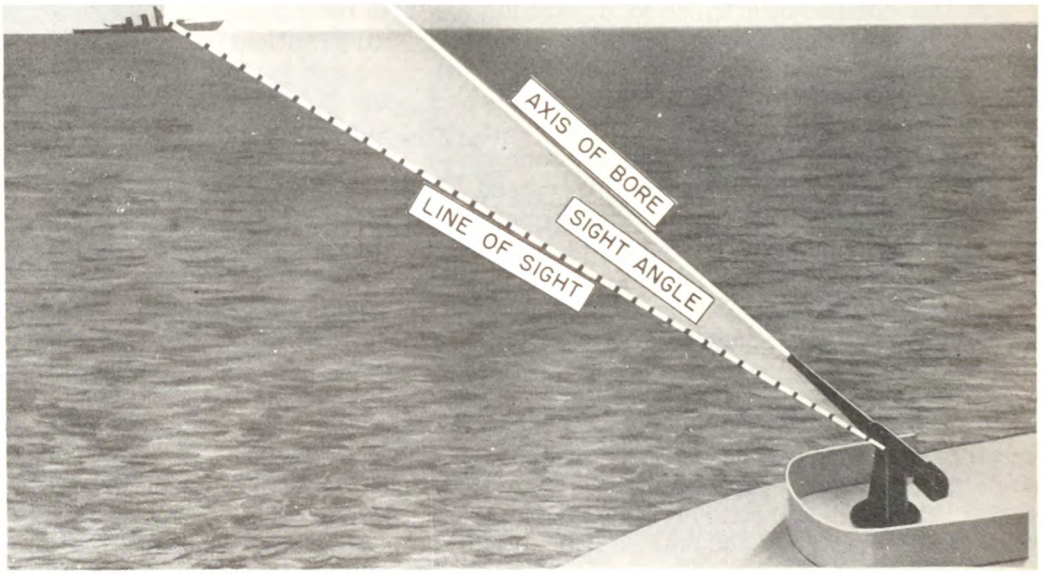

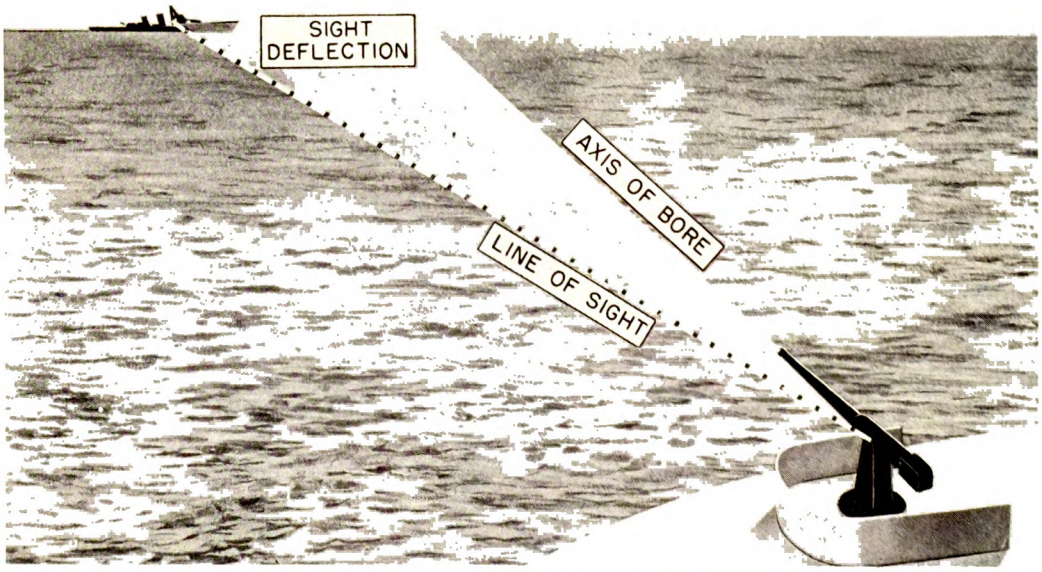

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Figure 5B13.—Offsets from LOS. A. Sight angle. B. Sight deflection. 84.198

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the amount the gun is elevated above the deck plane, and gun train order is the amount the gun trains in the deck plane measured clockwise from the ship's bow. Gun train and elevation orders are outputs from the system computer, and their principle computed variables, respectively, are sight deflection and sight angle.

Now consider the effects of fire control variables on sight angle and sight deflection, and on elevation and train gun orders of which they are part.

BALLISTIC VARIABLES. In the following list of ballistic variables we indicate the effect on sight angle and sight deflection of increasing the variable.

Variable	How compensated as variable increases
Projectile momentum	
(a) Mass (weight)	Increase sight angle.
(b) I.V.[1]	Decrease sight angle.
Gravity (itself a constant, but its effect is a function of time of flight).	Increase sight angle with increased time of flight.
Air resistance	Increase sight angle.
Wind	Depends on wind direction. If wind tends to increase range, reduce sight angle (and vice versa); add deflection and sight angle as needed for cross winds.
Drift	Add left deflection.
Earth's rotation and curvature.	Varies with range, latitude of gun, gun bearing. Both sight angle and deflection may be affected.

[1] In practice, as the gun wears I.V. decreases, hence sight angle must be increased to compensate.

CORRECTION FOR TARGET POSITION AND TARGET MOTION. For a stationary surface target and stationary own ship, once you know target position (bearing and range) you need lay the gun only for ballistic and wind corrections to put your projectiles on target. For a stationary air target you would have to add target elevation to the problem. Figure 5B15, part A, shows

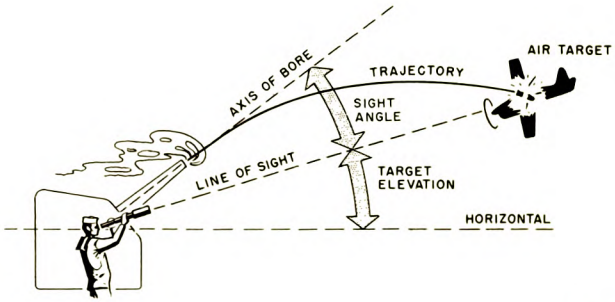

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Figure 5B14.—Target elevation and sight angle.

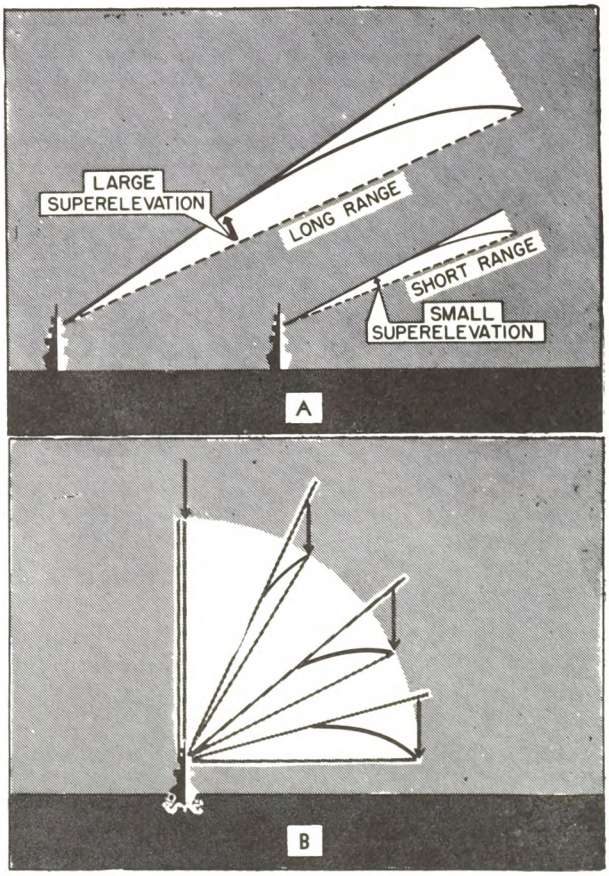

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Figure 5B15.—Effect on superelevation: A. Increased range. B. Increased target elevation.

that for a given target elevation the superelevation angle is large for long ranges. This is not new. But notice what part B shows. Assuming

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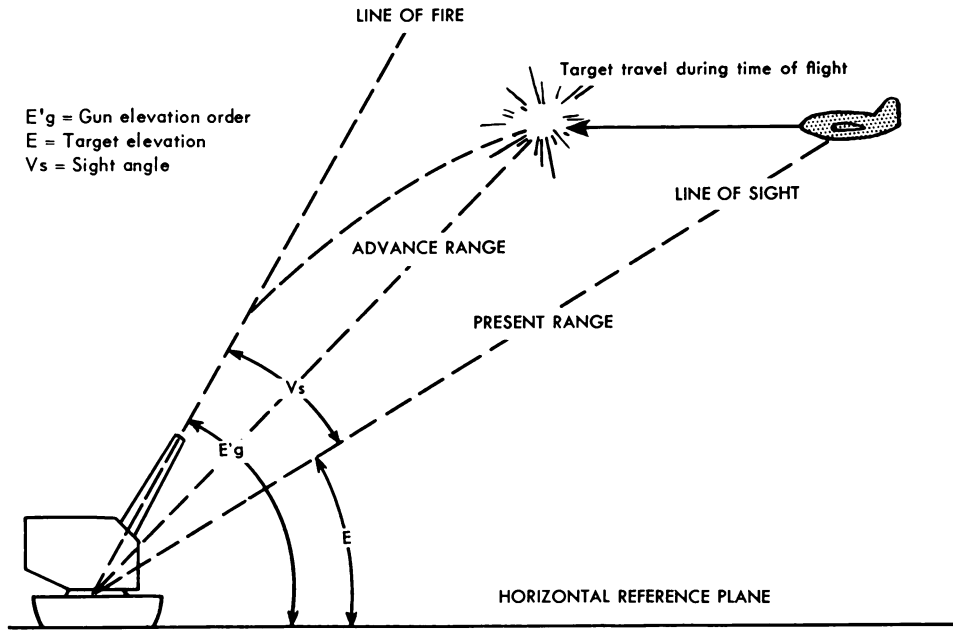

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Figure 5B16.—Basic angles in gun elevation order.

constant slant range, superelevation gets smaller as target elevation increases. To put it precisely, superelevation varies directly as the cosine of target elevation. If you could fire directly overhead, superelevation would be zero.

Now let us look at a moving target as in figure 5B16. This figure only shows the basic elements in gun elevation order. Notice that the ship's deck is assumed to be horizontal (rarely the case), and that superelevation is not shown in the figure. You will recall that superelevation is a part of Vs, or sight angle. Figure 5B17 shows the relationship of the various angles in gun train order. These angles are easily understood. We will discuss one or two items, however, which may be new to you. First, notice that Br and B'r are shown as equal angles. This is true only when the ship's deck plane is in the true horizontal, that is, when there is no roll and no pitch. B'r is measured in the deck plane as denoted by the prime in the quantity. This is also true of B'gr, while the other angles shown are measured in the horizontal plane. The second item concerns Ds. Notice that Ds is correcting for the target's travel during time of flight of the projectile, and the drift of the projectile. The correction in our illustration is in the same direction for both factors. If the target were proceeding on an opposite course, Ds would be the algebraic sum of the corrections for drift and the target's travel during time of flight since the drift correction is always to the left. In the situation shown in the figure, the angle B'gr is less than the angle B'r, and it is less by the angle Ds. (There are various other angles in fire control, which have been omitted for simplicity in figures 5B16, and 5B17.)

Inherent corrections. As you remember, correction for motion of the gun platform, parallax correction, and roller path compensation have been lumped under the heading "inherent corrections."

We correct for motion of the gun platform (i.e., ship's pitch and roll) by relating it to a gyrostabilized horizontal reference. You remember from chapter 3 that one of a gyroscope's characteristics is its tendency to maintain a stable attitude in space (the other, used in gyroscopic computers, is its tendency to precess when the direction of its shaft is changed). In different gun fire control systems the gyroscopic mechanism that does this is called "stable element," "stable vertical," or "vertical gyro," but the principle is the same. The gyro maintains a fixed vertical attitude; electrical pickoff

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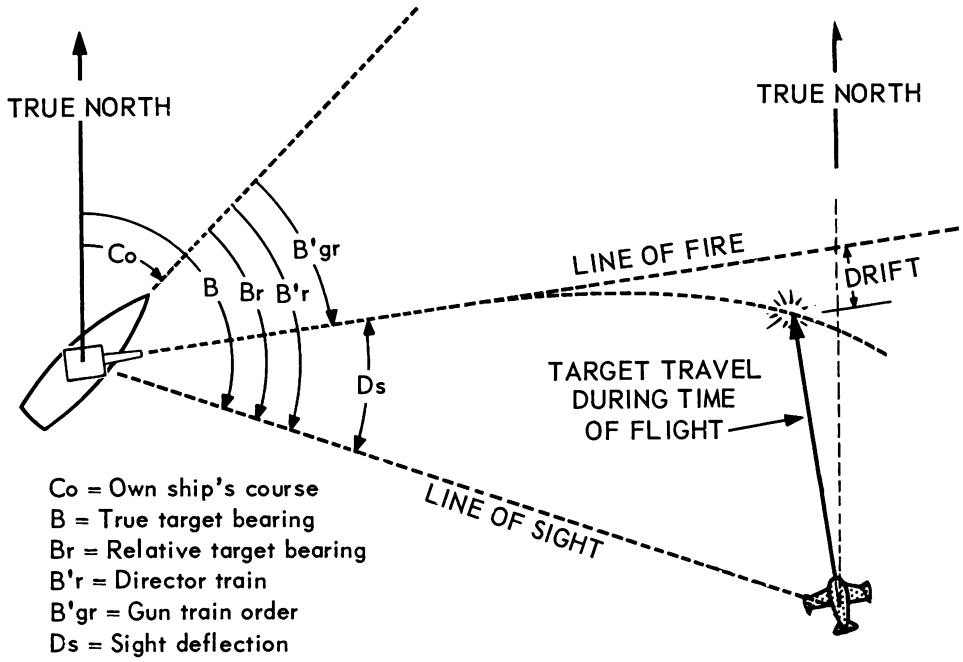

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Figure 5B17.—Basic angles in gun elevation order.

units (which roll and pitch with the ship) continuously sense their angular displacement with respect to the stable gyro axis, and produce a corresponding signal. The gyro unit receives director train angle as an input; its main outputs are level angle and crosslevel angle. Figure 5B7 shows level and crosslevel.

These quantities are combined in the computer along with the ballistic and target movement (lead) corrections to make up sight angle and deflection; these, in turn, become part of the gun orders to the mounts.

Horizontal parallax corrections, as pointed out earlier in this section, are computed on the basis of a standard unit correction which is then converted at each gun mount to the proper value for that mount. Horizontal parallax correction is usually transmitted independently of gun order to the gun mounts. Vertical parallax is considered equally applicable to all mounts, since their height variations are small, and is transmitted as part of sight angle.

Roller path correction is taken care of entirely by the mount compensator mechanisms mentioned earlier.

How the guns are positioned. You already know that in most mounts larger than 20-mm the guns are positioned by electric or electric hydraulic power drives. They may be positioned in automatic control (i.e., by the power drives under the complete remote control of the computer or director), in local control (by the power drives under the control of the mount crew), in manual control (by the muscular effort of the mount crew), or in hand control (in some 5-inch electric-hydraulic mounts only; the hydraulic elements of the power drive are directly controlled by the crew). Automatic control is the preferred and commonest mode; others are used either in mount adjustment or for emergencies and in training for emergencies.

As they come from the synchro transmission wiring the gun order signals are fed to an indicator-regulator or a receiver-regulator. These perform pretty much the same function; they are the control element of the power drive (which, as you recollect from chapter 3, is fundamentally a servomechanism). The distinction between indicator-regulators and receiver-regulators is not significant functionally. From here on we'll

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refer to indicator-regulators exclusively. Naturally there is a separate indicator-regulator for the train power drive and for the elevation power drive in each mount.

The gun order synchro signal is usually dual-speed; that is, it consists of two separate signals, one low-speed (coarse) and one high-speed (fine). (These were explained in chapter 3.) The coarse signal is generally 1-speed (i.e., synchro rotation bears a 1:1 ratio to the value being transmitted), though in some systems a 2-speed coarse signal is used for elevation (i.e., synchro rotation bears a 2:1 ratio to the value being transmitted, so that, for example, synchro rotation of 200 minutes occurs when an elevation value of 100 minutes is transmitted). In today's standard practice, the high-speed signal is 36 times the low-speed signal (i.e., the fine synchro rotor turns 360° for each 10° rotation of the coarse synchro rotor). In most synchro dual-speed transmissions, the fine synchro signal is then a 36-speed signal; in those with a 2-speed coarse signal, the fine signal is 72-speed.

Indicator-regulators now in service in gun mounts (other than bag-type major-caliber turrets, which we do not take up here) can be classified in the following general types:

1. Those with a hydraulic amplifier controlling a hydraulic A-end.
2. Those with an electronic amplifier controlling a hydraulic A-end.
3. Those with an electronic amplifier controlling an electric drive.

All 5''/38 mounts with power drives have the first type of indicator-regulator. The incoming gun order signal goes into synchro receivers; their rotors turn and actuate sensitive hydraulic pistons which control oil flow to more powerful pistons; these position the A-end tilt plate so that the B-end drives the mount in accordance with the signal. Mechanical feedback drives the synchro stators to null position.

The second type of indicator-regulator (or receiver-regulator) is used in some turrets, in late type automatically loaded 5''/54 mounts, and in 40-mm mounts. In this type the incoming synchro signal goes to synchro control transformers which convert it into an a-c voltage whose phase and magnitude are proportional to the angle of the synchro control transformer rotors with respect to their stators. This a-c voltage is then fed into an amplifier. (In dual-speed systems, an electrical "synchronizing network" feeds the sum of the two rotor signals to the amplifier, but disconnects or suppresses most of the fine synchro output if the gun deviates from gun order position by more than a few degrees.) The amplifier may be of the conventional vacuum-tube type, it may use transistors instead of tubes, or it may combine a tube or transistor preamplifier with a magnetic amplifier. Its output drives a motor, which regulates a pilot piston, that positions or controls the position of the hydraulic A-end. The remainder of the cycle (including mechanical feedback to the synchro control transformers) is similar to the first type described.

In the third type, synchro control transformers, synchronizing networks, and amplifiers function as in the second type, but the amplifier output goes to an amplidyne drive system (something like an electrical A-end and B-end) described in chapter 3. Again, mechanical response drives the synchro stators to null.

HOW THE GUNS ARE FIRED. Fire control does not end with control of gun aim: it also includes control of actual firing. This means initiating the firing impulse, and originating (or relaying) the operational commands to gun crews. Generally, when a gun power drive is in automatic to be controlled by a gun director or a plotting room, its firing circuit is activated by whichever station is in control. Antiaircraft batteries are almost always fired by their respective directors. A dual purpose battery is fired from its director or the stable element in the plotting room, depending on the type of firing engagement, and depending on whether direct or indirect aiming is required. A general rule here is that when indirect-fire is used (i.e., the LOS is established by the use of maps and charts in the plotting room), firing is controlled by plot. (Indirect-fire is used only against shore targets.) This general rule works for a surface battery too, when it is engaged against shore targets, or perhaps aircraft.

Surface fire against waterborne targets is just a little different. A surface target has a zero elevation angle, which means that the director pointer (the crewman who normally measures elevation) can be released from establishing the LOS in elevation. The required gun elevation is automatically established when the correct value of range is set into the computer. (Other switching at the computer is necessary but will not be discussed here.) In this setup the pointer will not know when the system is on target, so control of firing is from the stable element in plot. The stable element was

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selected because it is the only device in the system capable of measuring the two remaining variables in the problem--roll and pitch. The director measured bearing and range, and when compared to roll and pitch they are nearly constant; or at least predictable. We can assume that the system will be on target in bearing and range at the instant of firing.

Most of the time the followup devices in the stable element will be in automatic. This mode provides continuous measurement of level and crosslevel which are then sent automatically to the computer. Since level and crosslevel become part of the gun orders, the guns are stabilized regardless of the ship's roll and pitch. If the firing selector switch on the stable element is in the "continuous" position, and if the level and crosslevel followups are in automatic, the guns can be fired at any time during ship's roll and pitch by closing a hand firing key on the stable element. The hand firing key is not electrically dependent on the followups, but it wouldn't be closed until level and crosslevel were accurately measured. Level and crosslevel are measured automatically by followups, or manually by handcranks. The latter method is used in emergencies for continuous measurement in case the followups become inoperative, and for two other firing modes called selected-level and selected-crosslevel, which we will now discuss.

When the sea is very rough, automatic followups may not be able to provide a continuous, accurate measurement of level and crosslevel. Even if they can, the gun power drive may not be able to keep up with the changing gun order signals. Or, the changes may be so great that they drive the gun into its firing cutout limits, and that opens the firing circuit. Under these sea conditions we could probably increase accuracy by removing the level and crosslevel inputs to the gun orders and allowing the gun to roll and pitch with the ship. At least we would eliminate the chances for error mentioned in this paragraph.

Level or crosslevel, one or the other, will have a larger variation, depending on the bearing of the gun and the roll and pitch of the ship. It is usually possible to leave the smaller variable in automatic and depend on its followup. An arbitrary value for the larger is "selected" at the stable element (stable vertical for turrets) and becomes a stationary input to the computer. The selected quantity must permit the gun to be correctly aimed at some point between the observed limits of the ship's roll and pitch; usually about the midpoint. Electrical contacts on the stable element automatically close the firing circuit (if the stable element automatic firing key is closed) at the instant ship rolls or pitches to the selected level, or to the selected crosslevel. The method of fire is chosen by the stable element operator who may operate his firing selector switch to the continuous, selected-level, or to the selected-crosslevel position.

5B10. OBSERVATION AND CORRECTION OF FIRE

Although the preceding discussion of fire control has referred often to the desired ideals of accuracy and speed in solution, and has at least hinted (it has not been possible to describe or even to refer to them all) at the refinements in modern fire control systems, it is still true that not all the factors which affect the flight of a projectile can be precisely evaluated in advance of firing. Even with the best fire control equipment available, experienced gun crews, and efficient fire control personnel, the opening shots may not hit the target. It is therefore necessary to apply corrections (or spots) to the initial firing data.

The initial spot is based on a system analysis of inherent errors. Even though the initial spot is figured precisely, external ballistic factors may still cause projectiles to miss the target. When this happens spots (based on where the rounds hit in respect to the target) are applied to subsequent salvos. Spotting is taken up in further detail in chapter 7 of this book.

5B11. SECONDARY METHODS

So far in discussing fire control, we have concentrated on the primary methods of battery operation. These are the ones most commonly used, and the ones which permit employment of the ship's armament with the greatest efficiency. But battle damage, personnel losses, and accidents can disable any system to the extent that some secondary operating methods are essential if the system is to keep operating at all, even if not at full efficiency. Aboard ship you will not only employ such methods in battle operations, but also in training for such emergencies.

All 3" gun mounts and larger are equipped with adjustable sights. With these, it is possible to offset the gun bore axis from the LOS to the

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desired sight angle and deflection. This function is performed by a crewman called the sightsetter, who mans the sight-setting indicator. In gun mounts 5-inch and larger, this unit contains handcranks and gearing for physically moving the sight optical units (or moving optical parts within the sights), and two sets of dials (fig. 5B18-A and B). One set, driven by the sight gearing, displays present sight angle and deflection. The others are synchro-driven to display sight angle and deflection ordered by the computer. (3"/50 mounts do not have the synchro-driven dials.) Even in automatic operation the sightsetter mans his station and cranks the sight gearing to keep the sight indicator dials matched up with the computer-controlled dials so that the LOS of the gun sights remains on target even though the gun bore axis is offset in accordance with the sight angle and deflection components of gun order. In 3"/50 and 5"/38 mounts, an extra range dial coupled to the sight angle crank reads directly in yards of range to a surface target.

In all types of secondary (local) control the gun must be laid by gun-laying personnel on the mount. In older types like 40-mm and 5"/38 mounts the pointer on the left side of the mount elevates and depresses the gun while the trainer (on the right) trains the mount. Each gun layer has a gun sight. They may either control the mount power drive or position the mount by their own muscular effort (manual operation).

In 3"/50 RF (rapid-fire) mounts, and automatically loaded 5"/54 mounts, there is no provision for completely manual operation. The mount can be operated in local, but only if the power drive is functioning. Manual operation is limited only to maintenance and stowing movements. In such mounts, either of the gun layers can take over complete local control of gun positioning.

In local control, gun layers must work with the sightsetter. Here is the basic procedure:

1. The gun layers position the mount so that their lines of sight are on target, and they continue positioning it to keep on target.

2. Most mounts have synchro-driven dials (as in fig. 5B18, part B) which indicate computed sight angle and deflection. The sightsetter cranks in sight angle and deflection until the outer dials (positioned by his handcranks) match the inner (synchro-driven) dials. This action simultaneously repositions prisms in the sight optical systems, causing the telescope lines of sight to shift off target.

3. The gun layers drive the mount to keep on target. This automatically offsets the gun bore axis by the angles that the sightsetter has cranked in.

Figure 5B18, part A, shows the handcrank arrangement; part B shows in more detail how the dials look when matched. The fixed index shows the angular values actually cranked in. It is used when there is no synchro transmission; under these conditions, the information is either transmitted by phone or comes from the mount captain, based on his estimate of range, ballistic corrections, and lead.

On mounts 5-inch and larger, the sights are carriage mounted. The sights therefore train with the carriage, but the carriage doesn't elevate. To make the sights elevate with the gun, they must be driven by a mechanical linkage from the elevating gear. Thus the sight angle prisms in the optical systems must be positioned by the algebraic sum of two inputs—gun elevation and sight angle. This is the function of a mechanical differential in the sight angle gear train.

Mounts smaller than 5-inch have slide-mounted sights, which elevate and train with the gun barrel. The differential is not needed. Nor do mounts smaller than 5-inch have synchro receivers for sight angle and deflection. When necessary, computed sight values are transmitted by phone.

When the gun bore axis offset is correct, the gun layers have been staying on target, and the gun is loaded, the gun can be fired by the pointer's firing key. This may be done on the mount captain's command. In the complete absence of firing current or if the ammunition fails to fire electrically, most 5-inch guns can be fired by percussion when the pointer depresses a firing pedal which actuates a mechanical linkage to the firing mechanism. Combination primers in the ammunition are necessary to provide this capability.

Secondary methods in the director and in fire control plot. In earlier linear-rate systems, the director can be driven manually in event of power drive failure. Range, bearing, and elevation data can be sent to plot by telephone if synchro transmission fails, as can firing orders to the mount if the firing circuit fails. In the event of stable element failure, some older fire control systems can be stabilized manually by a crewman who keeps a telescope LOS aligned with the horizon.

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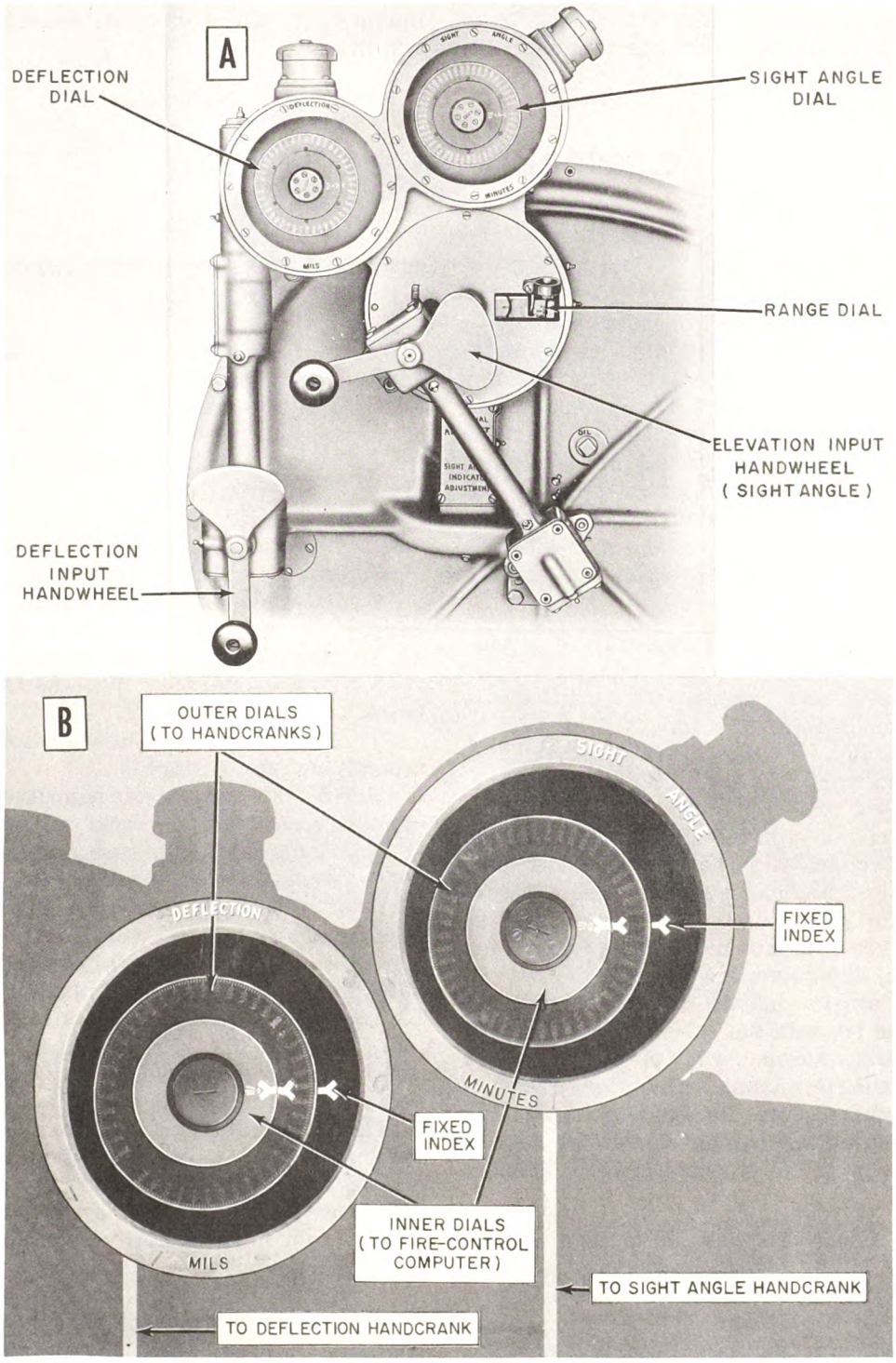

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Figure 5B18.—A. Sight setting component arrangement. B. Sight angle and deflection dials.

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If synchro transmission fails with any computer inputs or outputs, data can be introduced manually or read from dials and telephoned from plot, but neither stable element nor computer can function without the proper supply. When any failure prevents data from reaching the gun mount, secondary methods must be used at the gun mount.

C. 5"/38 Guns and Mounts

5C1. INTRODUCTION

The 5"/38 gun is one of the most widespread naval weapons in the fleet. It is not a new design, but its reliability and the essential soundness of its design have continued its usefulness into a day when it is far outranged by spectacular new weapons. Many of its design features persist in the very newest gun designs in the fleet, but on the whole it can be considered the prototype of the "conventional U. S. naval gun." It is the weapon characteristically used with linear-rate fire control systems.

The 5"/38 gun appears in the following general types of mounts:

1. Enclosed twin mount with ammunition-handling room beneath the mount. The type of mounts is a standard installation on many cruisers, and destroyers, and some aircraft carriers.
2. Enclosed single mount with ammunition-handling room beneath the mount. This is the old standard destroyer-type mount. It is now found on many minecraft and auxiliaries developed from the older classes of destroyers, on destroyer escorts, and on many large auxiliaries (repair ships, destroyer tenders, etc.).
3. Open single mount with ammunition-handling room beneath the mount. This mount is used on auxiliary ships.
4. Open single mount without ammunition hoists or handling room. Because mounts of this type can be installed without extensive reconstruction, it is used on converted merchant vessels.

Another mount similar in design to the 5"/38 is the 5"/54 (Mk 39), which is used on Midway class aircraft carriers. It has a longer barrel and an amplidyne all-electric power drive in contrast to the electric-hydraulic power drive used in all 5"/38 mounts. Do not confuse this mount with the automatic-loading 5"/54 (Mk 42) which is covered later.

5C2. GENERAL DESCRIPTION OF 5"/38 MOUNTS

The 5"/38 caliber gun is a semiautomatic, dual purpose, base-ring-mounted gun which uses semifixed ammunition. Its principal features are:

1. Vertical sliding-wedge breech mechanism.
2. Hydraulic recoil and hydropneumatic counterrecoil systems.
3. Power-operated rammer.
4. Power-operated elevating and training gear.
5. Movable-prism telescopes.
6. Power-operated fuze-setting projectile hoist.
7. Power-operated powder hoist on all twin mounts and some singles.

The 5"/38 mount uses semifixed ammunition consisting of a 54-pound projectile (weight varies somewhat with type of projectile) and a case assembly weighing about 28 pounds, which includes a 15-pound powder charge. Ballistic performance obtained with a 15-pound service charge (full charge) is as follows: initial velocity, 2600 feet per second; maximum horizontal range, 18,000 yards; maximum vertical range, 37,300 feet. (The Mk 39 5"/54 uses heavier ammunition and has longer ranges.) The gun is capable of sustained firing at a rate well in excess of any which can be attained by the loading crew. An experienced crew can load about 15 rounds per minute for long periods, and may attain a short-period rate of 22 rounds per minute.

The gun has a radially expanded 2-ton steel monobloc barrel. The rifling has a uniform twist of 1 turn in 30 calibers. The bore is chromium plated from the forward portion of the powder chamber to the muzzle. The barrel is connected to the housing by a bayonet-type joint.

The housing (fig. 5C1) is a rectangular block-shaped forging, with forward portion machined to receive the barrel. In the center is a vertical

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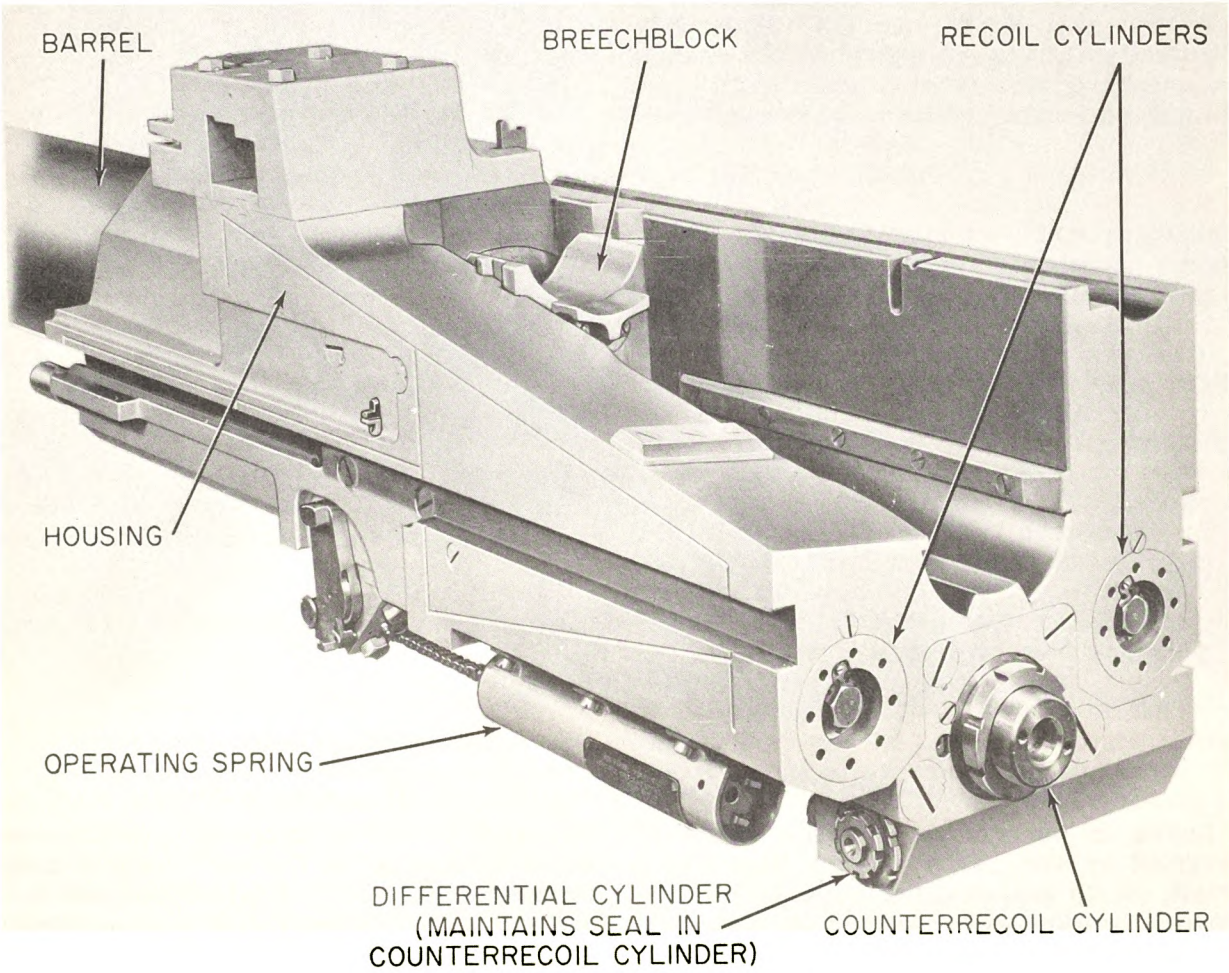

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Figure 5C1.—5-inch housing and gun (removed from slide).

well for the breechblock; and to its rear is a trough-like ammunition-loading tray. The housing contains twin interconnected recoil cylinders (groove type) and a single counterrecoil cylinder. The housing supports and locks the gun in the slide, and moves on the slide guides during recoil and counterrecoil.

The slide (fig. 5C2) is a large box-shaped weldment, open at top and bottom, within which the housing moves in recoil and counterrecoil. The housing is supported and guided by two guide rails bolted to the inner side plates. The elevating arc and the rammer are secured to the slide. Other mount structure details resemble those of conventional practice described in chapter 4.

Other characteristics of 5''/38 mounts. All enclosed mounts are housed in a shield of armor plate. The shield is a box-like structure that provides weather, blast, and splinter protection for the crew.

Through doors on both sides near the after end, the operating personnel enter or leave the mount. Other doors and access cover plates provide for inspection and repair. A roof hatch may be located near the after end of the gun mount. Where necessary, this hatch has a blast hood. Sight hoods on the side shield plates protect the three sight telescopes. A ventilation system supplies air to the mount and handling room.

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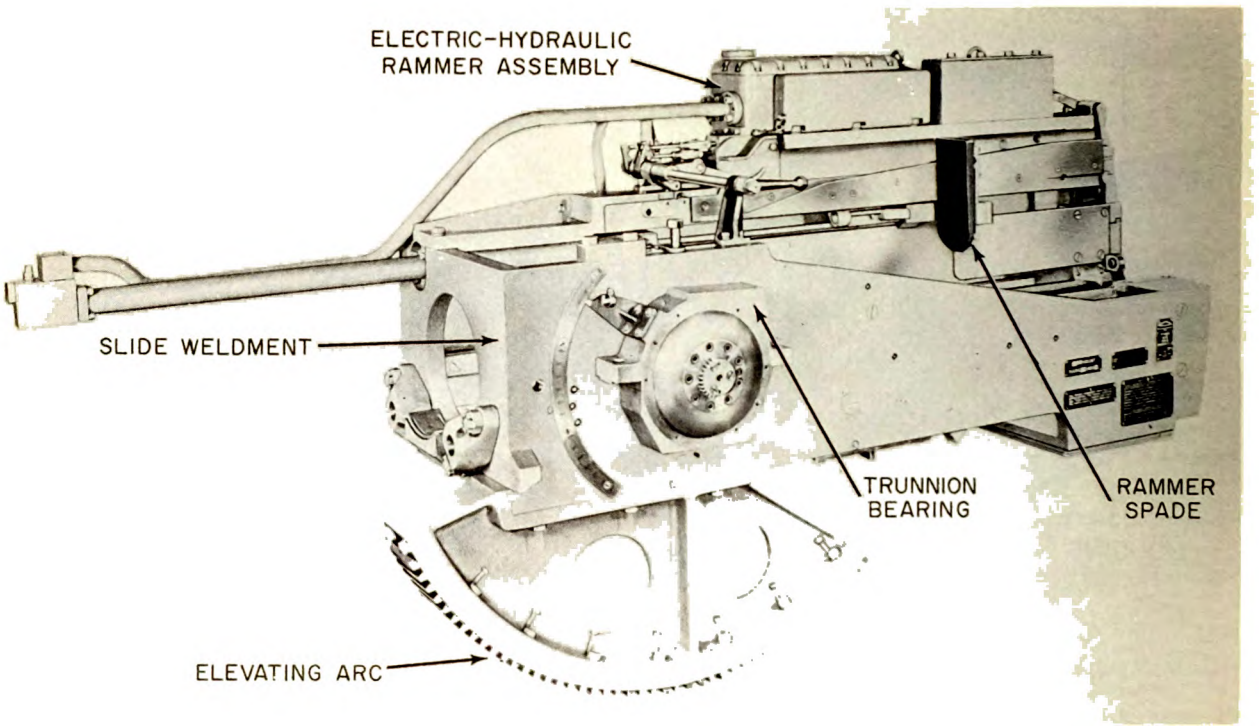

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Figure 5C2.—5-inch slide removed from mount and minus gun and housing.

Lights in the gun and handling room are energized by the ship's general illumination circuit, which also includes outlets for battle lanterns, window-wiper motors on each sight telescope, and the battle illumination system, which energizes small lamps at all instruments and controls.

Gun elevation, gun train, fuze setting, and sight setting synchro signals are supplied to the indicator-regulators and the sightsetter's indicator in the mount by fire control circuits from the computer.

Communication facilities in 5''/38 mounts may include (1) a voice tube between gun room and upper handling room, (2) an automatic telephone in the ship's general communications system, (3) a sound-powered battle phone circuit between mount and fire control stations, (4) an auxiliary sound-powered phone circuit with call bell between mount and lower ammunition-handling room, and (5) a loudspeaker connected to the director and plotting room.

5C3. BREECH MECHANISM

The important parts and the operating cycle of the 5''/38 breech mechanism are shown in figures 5C3 and 5C4. In operating principles and general construction the mechanism is similar to that of the 3''/50, and in lesser degree though still to a significant extent it resembles the breech mechanisms of the rapid-fire 5''/54 Mk 42, the 6''/47 turret case guns, and the 8''/55 turret case guns.

The breechblock is a steel block which can slide up and down on guides in a breechway in the housing. It is positioned by an operating shaft in the housing. The thrust of a coil spring as exerted through a chain on the shaft tends to drive the block upward to closed position. The salvo latch on one end of the crank locks the mechanism in breech-closed (breechblock-up) position; it is unlocked either by a cam on the slide or manually (if necessary). The block is forced down to breech-open position during counterrecoil by another cam on the slide which engages the lug on the crank during counterrecoil. The block is locked down by a pair of extractors, one on each side of the block. A hand-operating mechanism (not illustrated) provides for manual operation of the breech mechanism. The breech must always be opened by

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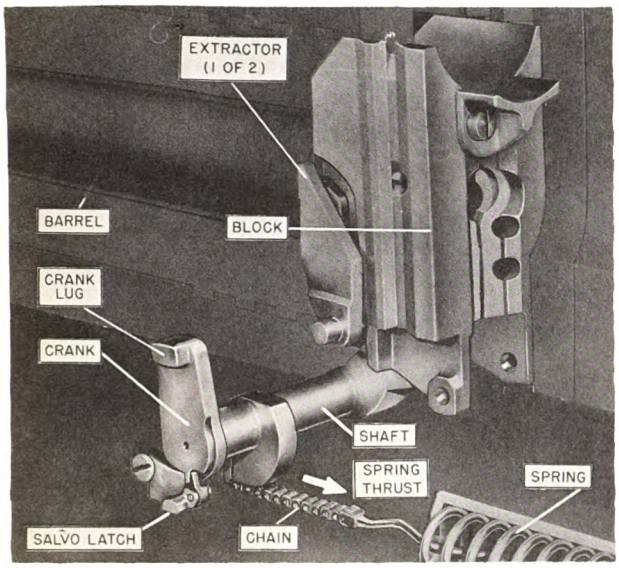

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Figure 5C3.—5-inch breech mechanism parts, breech closed.

hand to start firing; hand operation is also required in maintenance operations, and when mechanical failure makes semiautomatic operation impossible.

Now follow the breech mechanism operating cycle. Some details are omitted for the sake of clarity.

1. (Fig. 5C4, part A.) We start with breech open. Rammer (only the spade, which actually pushes the round, is shown in the figure) thrusts round into chamber. Rim of case engages extractor lips and pushes them forward, unlocking block.

2. (Fig. 5C4, part B.) Driven by breech-operating spring, block rises, wedging cartridge case into chamber. When breech is fully closed, salvo latch locks it closed. (Fig. 5C3 shows salvo latch locking mechanism in closed position.)

3. (Fig. 5C4, part C.) Gun ready to fire. It fires and recoils, but this diagram requires no change. However, salvo latch is cammed (not shown) to unlock breech (not to open it) during recoil.

4. (Fig. 5C4, part D.) Gun counterrecoils. Cam (not illustrated) on slide engages crank lug on operating shaft and rotates shaft, causing it to lower breechblock. As breechblock drops, extractors begin to rock rearward. Extractor lips still engage cartridge case rim, hence case is forced out of chamber.

5. (Fig. 5C4, part E.) Breechblock drops further, causing extractors to flip case out to the rear. When block is fully down, extractors remain in rearmost position and lock block down.

5C4. FIRING SYSTEM

The firing system of a 5"/38 mount closely follows conventional practice as described in the preceding chapter. There is a firing mechanism in the breechblock; its insulated firing pin is in contact with the cartridge primer only when the gun is loaded, the breechblock is closed, and the gun is in battery. A foot-firing mechanism permits firing the primer by percussion, but this is rarely done. The standard method is to use the firing circuit. The pointer has a key which closes the secondary circuit of the firing transformer; the mount captain has a switch to permit selection of local or remote firing. In remote-control firing (which is most usual), the pointer's key is closed, and firing is controlled from either the director or plot.

The firing stop mechanism keeps the firing circuit open and the percussion firing linkage disconnected unless the gun is on an elevation and bearing at which the projectile will not hit the ship's structure.

5C5. GAS EJECTOR SYSTEM

Gas ejectors prevent entry of powder gases into gun mounts, safeguard against the danger of flarebacks, and assist in maintaining a rapid rate of fire by clearing the bore of gases. Air under pressure of approximately 75 pounds per square inch is piped from the ship's supply to nozzles in the breechblock guideways pointed toward the gun bore. During counterrecoil, a gas ejector valve in the housing is cammed open and gas ejection begins. The valve is closed by the rammer as the next round is rammed. A hand lever permits manual opening and closing of the valve.

5C6. RAMMER AND AMMUNITION HANDLING CYCLE

The rammer is a semiautomatic electric-hydraulic unit on the upper rear part of the slide. A 7 1/2-hp electric motor drives a pump whose output is controlled by valves to operate the ram

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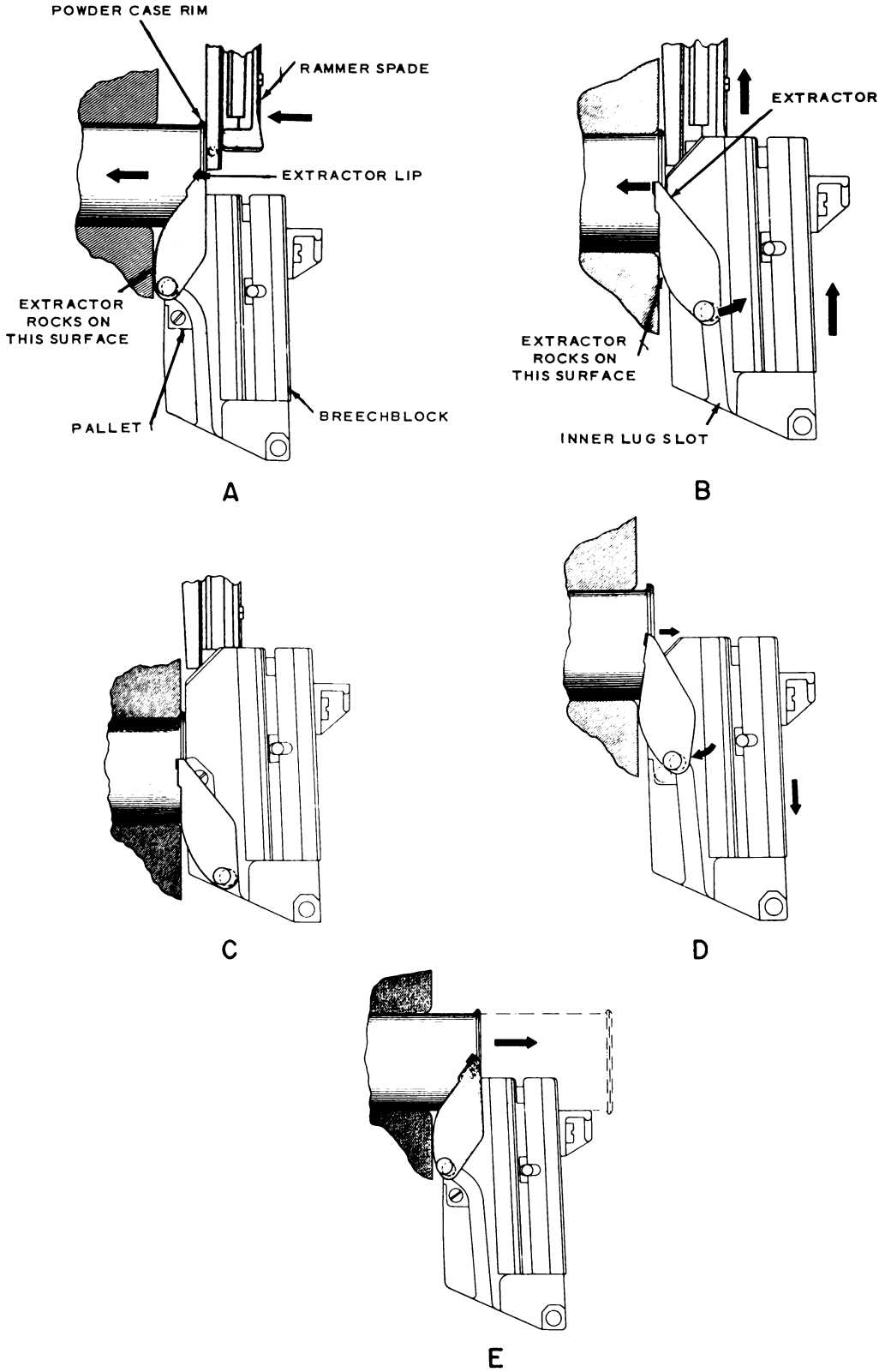

Figure 5C4.—5-inch breech mechanism operating cycle. 84.160

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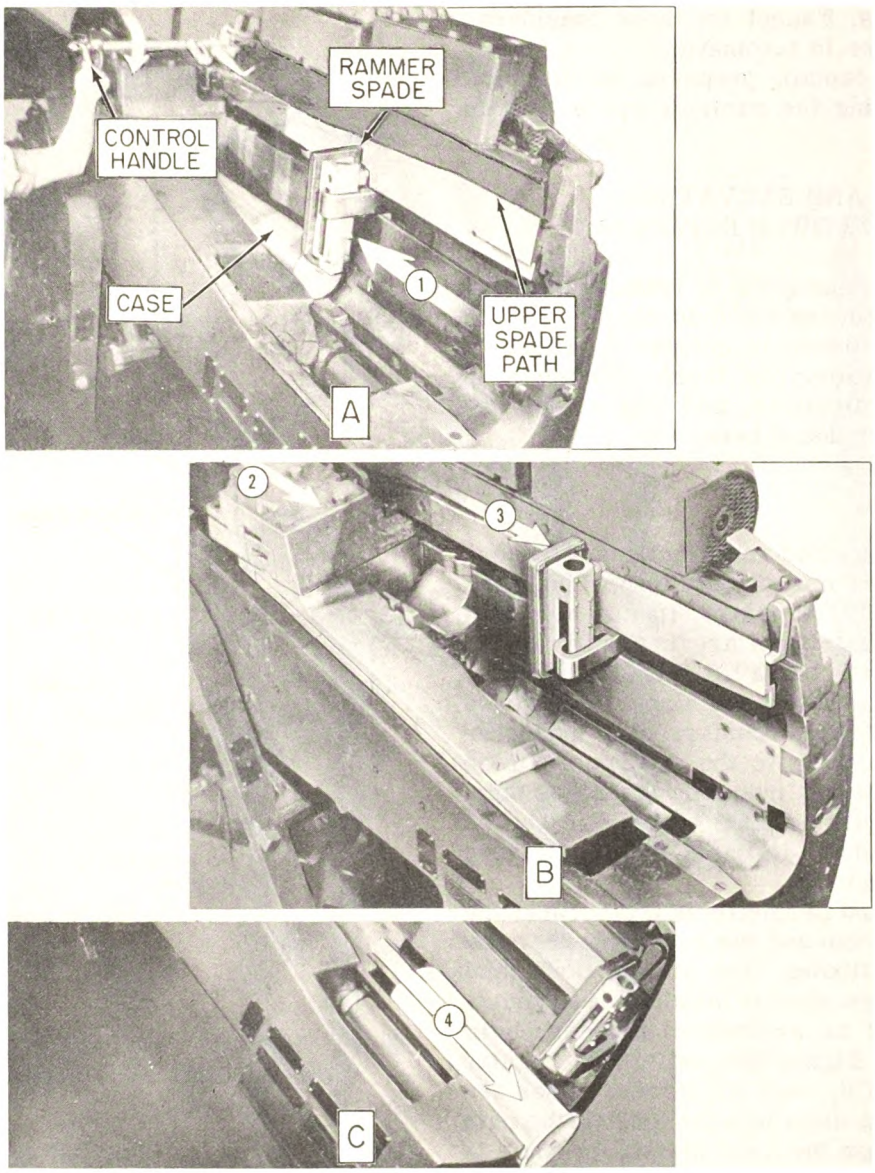

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Figure 5C5.—5"/38 mount. Loading and extraction operations.

cylinder. The piston of the cylinder is mechanically linked to a rubber-faced rammer spade which moves forward along the loading tray, and to the rear in an elevated path along the slide. The cycle of operation is as follows:

1. Two crewmen (the projectileman and powderman) take the projectile and powder case out of their hoists and deposit them in the loading tray in the slide.

2. The rammerman depresses a control handle (fig. 5C5, part A). The ram cylinder forces the rammer spade forward (arrow (1)) to ram the round into the chamber.

3. When the breechblock closes and the gun fires and recoils (arrow (2) in fig. 5C5, part B), the rammer spade is automatically retracted (arrow (3)) along an upper path in the slide. This lifts the spade so that it will not obstruct the extracted cartridge case's path (arrow (4), fig. 5C5, part C) to the rear. A crewman throws the fired case out of the mount in single mounts, and in twin mounts when gun elevation exceeds

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about 30 degrees. Except for these considerations case ejection is automatic.

4. The gun captain prepares for the next round by lowering the rammer spade to ram position.

5C7. TRAINING AND ELEVATING GEAR AND POWER DRIVES

The general principles of training and elevating gear were explained in chapter 4, and those of power drives in chapter 3. Those of 5"/38 mounts exemplify these principles in conventional applications, and will not be described in further detail here.

5C8. HOISTS

Chapter 4 described and illustrated as a conventional type the ammunition transport installation for a twin 5"/38 mount. In this arrangement, powder cartridges are manually loaded into dredger hoists which lift them to the upper handling room; here they are manually removed from their tanks and transferred to a powder hoist which lifts them to the gun house. In the gun house a crewman manually transfers them from powder hoist to gun slide. Projectiles typically are handled similarly, except that they are not stowed in tanks.

The powder and projectile hoists between the upper handling room and the gun house are quite different in functioning. The powder hoist (and dredger hoists are similar in principle) consists fundamentally of an articulated endless chain with supports or flights secured to it at regular intervals (fig. 5C6, part A). Powder cases are loaded by pushing them into the hoist in the path of the flights; when the hoist starts, the chain is driven upward until the next vacant flight is in loading position. When the next unit is loaded, the hoist goes up one more flight, and so on. The hoist starts automatically when loaded. The hoist is driven by a rotary hydraulic motor whose functioning is controlled by valves.

Endless-chain hoists generally can be operated in reverse to lower ammunition units, as is required in taking ammunition aboard. In either mode of operation, the hoist moves one flight at a time, intermittently in the same direction. Only one side of the chain is used.

The projectile hoist, in contrast, has an endless chain in which both sides of the chain are used (fig. 5C6, part B). There are 2 flights, arranged so that when one is at the top of the

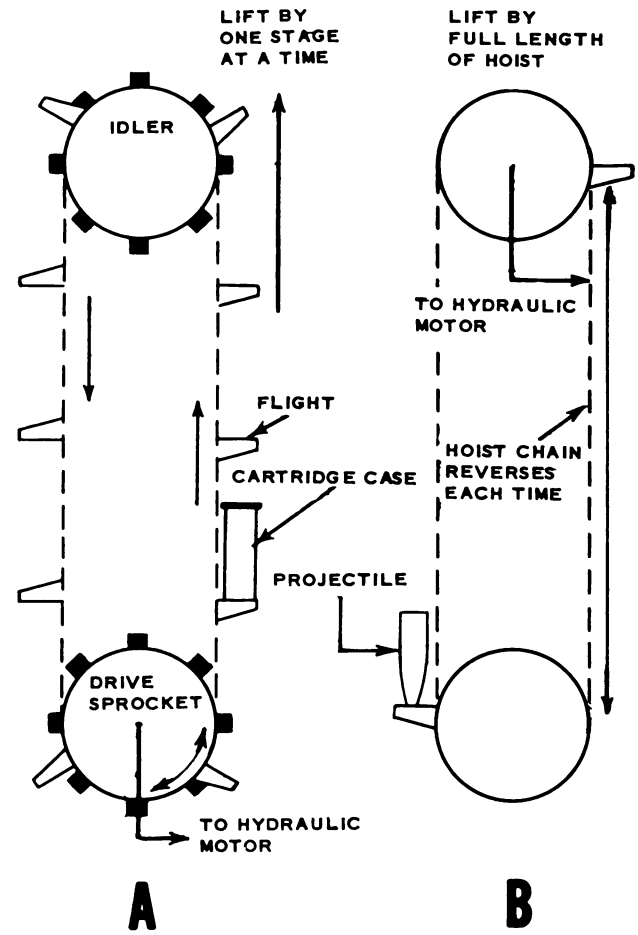

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Figure 5C6.—Principles of 5"/38 hoists. A. Powder hoist. B. Projectile hoist. (Fuze setter not shown.)

hoist on one side, the other is at the bottom of the hoist on the other. The chain runs first in one direction, then the other, and the flights always move from all the way at the top to all the way at the bottom (or vice versa), as in the old-time well with 2 oaken buckets, one of which descended while the other went up. The projectile is loaded into one side, and automatically the hoist starts if the top is empty. As the loaded flight ascends, the empty comes down. The cycle reverses for the next projectile.

In addition to hoisting projectiles (it is never used for lowering them), the 5-inch projectile hoist also sets the projectile fuze (when a projectile with time fuze is loaded). As you can see in figure 5C7, the projectile hoist has three chains. The center one is the hoist chain. It is

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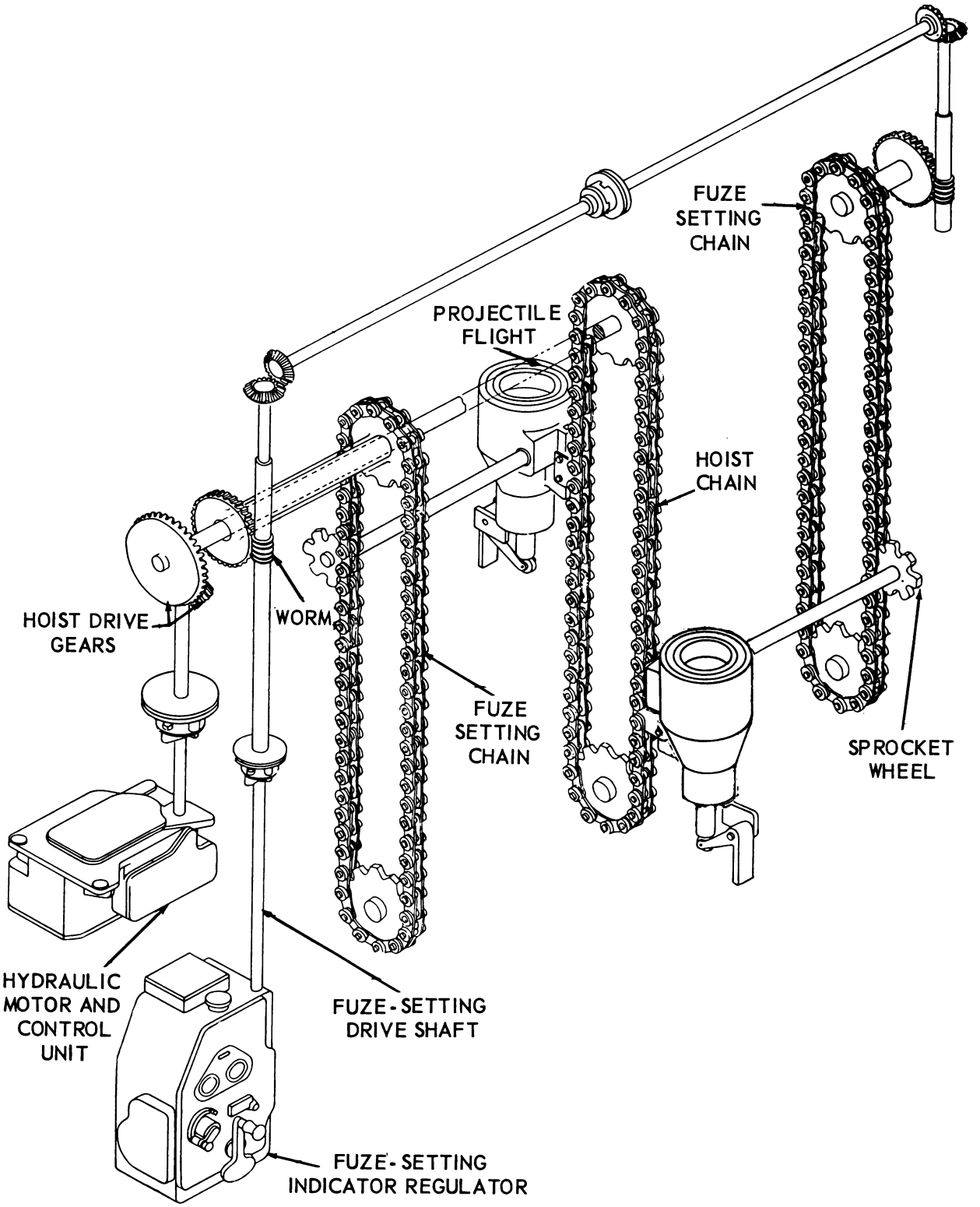

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Figure 5C7.—5-inch projectile hoist. (Schematic.)

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driven by a hydraulic motor through shafting that rotates a sprocket at the top of the chain. Each of the other two chains is part of the fuze setting linkage. They are positioned by the fuze setter indicator-regulator, a servomechanism controlled by the fire control computer. Each projectile flight has a small sprocket wheel which engages one of the chains. As the projectile flight is hoisted by the hoist chain, its wheel "walks" up the fuze setting chain. This rotates a ring (not shown) inside the flight. The projectile is manually loaded nose down into the flight. If it is a time-fuzed projectile, it is loaded so that a lug on the fuze engages the ring in the flight. As the projectile is hoisted, the fuze's lug is rotated by the ring. This adjusts the fuze to the desired time setting. So long as the projectile remains in the hoist, the time fuze setting is continuously adjusted by the fuze setting indicator-regulator through the fuze setting chain and ring. The time lapse from the instant the projectile is removed from the hoist (after which its fuze adjustment ceases) until it is fired is called dead time, which is estimated and included in the fire control computation.

This discussion of ammunition supply equipment has concentrated on twin mounts, which are the most elaborately equipped. Some single 5-inch mounts (for example, the single 5"/54 Mk 39 mount) are equipped with one powder hoist and one projectile hoist per mount. Other single 5"/38 mounts may have only a projectile hoist, plus (instead of a powder hoist) a deck scuttle through which powder cases are pushed by hand. Some auxiliaries are still equipped with open mounts with similar arrangements, or with no hoists at all, but this is not the normal condition aboard combat vessels in the active fleet.

5C9. SIGHTS

All enclosed 5-inch mounts, both twin and single, are fitted with carriage-mounted telescopic sights in which movable prisms in the optical system provide for offsetting the gun bore axis from the line of sight (LOS). All twin mounts have three sights—one for the pointer, one for the trainer, and one for a sight checker. However, there are but two optical systems—one for the trainer, and one that is shared by the pointer and checker. Each optical system has two movable prisms—one to introduce deflection, the other to introduce sight angle. The sighting system also includes a sightsetter's indicator operated by the sightsetter. These units and the mechanical linkages between them are shown in figure 5C8, which depicts and front of a twin mount with the shield removed.

The sightsetter's indicator is shown in figure 5C9. It has a sight deflection handcrank, a sight angle handcrank, and three sets of dials—a pair of deflection dials (one coarse, one fine), a pair of sight angle dials (one coarse, one fine), and a range dial. The indicator receives sight deflection and sight angle synchro signals from the computer. The deflection dials are calibrated in mils (6400 to the circle), with the zero point (i.e., gun bore axis parallel to LOS in a vertical plane) arbitrarily chosen as 500 mils on the dials. Sight angle dials are calibrated in minutes (21,600 to the circle) with the zero point (gun bore axis parallel to LOS in a horizontal plane) arbitrarily chosen at 2000 minutes. (Using these arbitrary values instead of zero eliminates the need for using signs to indicate the direction of offset.)

The range dial, which is geared to the sight angle handcrank, is calibrated in yards, and is used in emergencies against surface targets when no sight angle data are available from fire control plot.

The Mk 39 5"/54 single mount has a sight setup similar to that described above. The sight mechanism in all single 5"/38 mounts uses a different mechanical arrangement (which in its end results functions much as in the twin, however), and while some 5"/38 mounts use prismatic sights, others use sight telescopes which have fixed optical systems and are therefore shifted as complete units for sight angle and deflection.

5C10. 5-INCH MOUNT CREW

Figure 5C10 shows the crew station at the 5"/54 Mk 39 gun house level. The Mk 39 is like the 5"/38 mounts in crew arrangement and duties.

The mount captain is the command leader. If available a gunner's mate is his principal assistant and supervisor of gun operation. He serves as troubleshooter and chief maintenance man. The pointer is responsible for checking and operating his sight and (when not in automatic) the elevating gear; he also, in most cases, fires the gun. The trainer does similarly for his part of the mount except for firing the gun. The sightsetter receives and sets sight deflection and sight angle. The fuze setter tests the fuze-setting mechanism, and operates it

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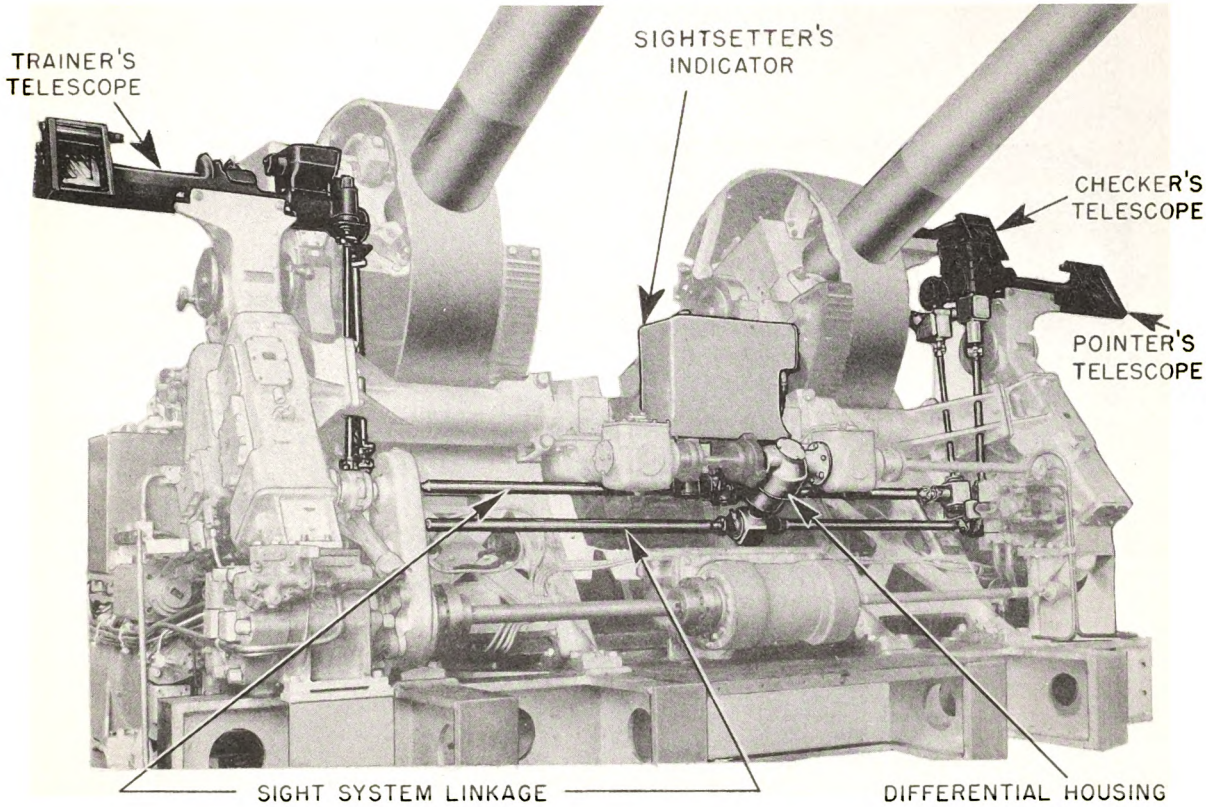

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Figure 5C8.—5"/38 twin mount. Shield removed to show sight components as viewed from front of mount.

when not in automatic. The projectile-and-rammerman operates the rammer, and loads projectiles. The gun captain lowers the rammer spade and checks the loading operation. The powderman takes the cases out of hoist and passes them to the loader-hot-case man, who puts the cases in the slide.

In addition to these ten men in the gun house, there are six in the upper handling room (not diagrammed). Two powdermen keep the powder hoist supplied, two projectilemen do the same for the projectile hoists, and two others operate scuttles through which ammunition is passed from the magazines.

In a twin mount many of these crew stations are duplicated because there are two guns and two sets of hoists. The crew totals 27.

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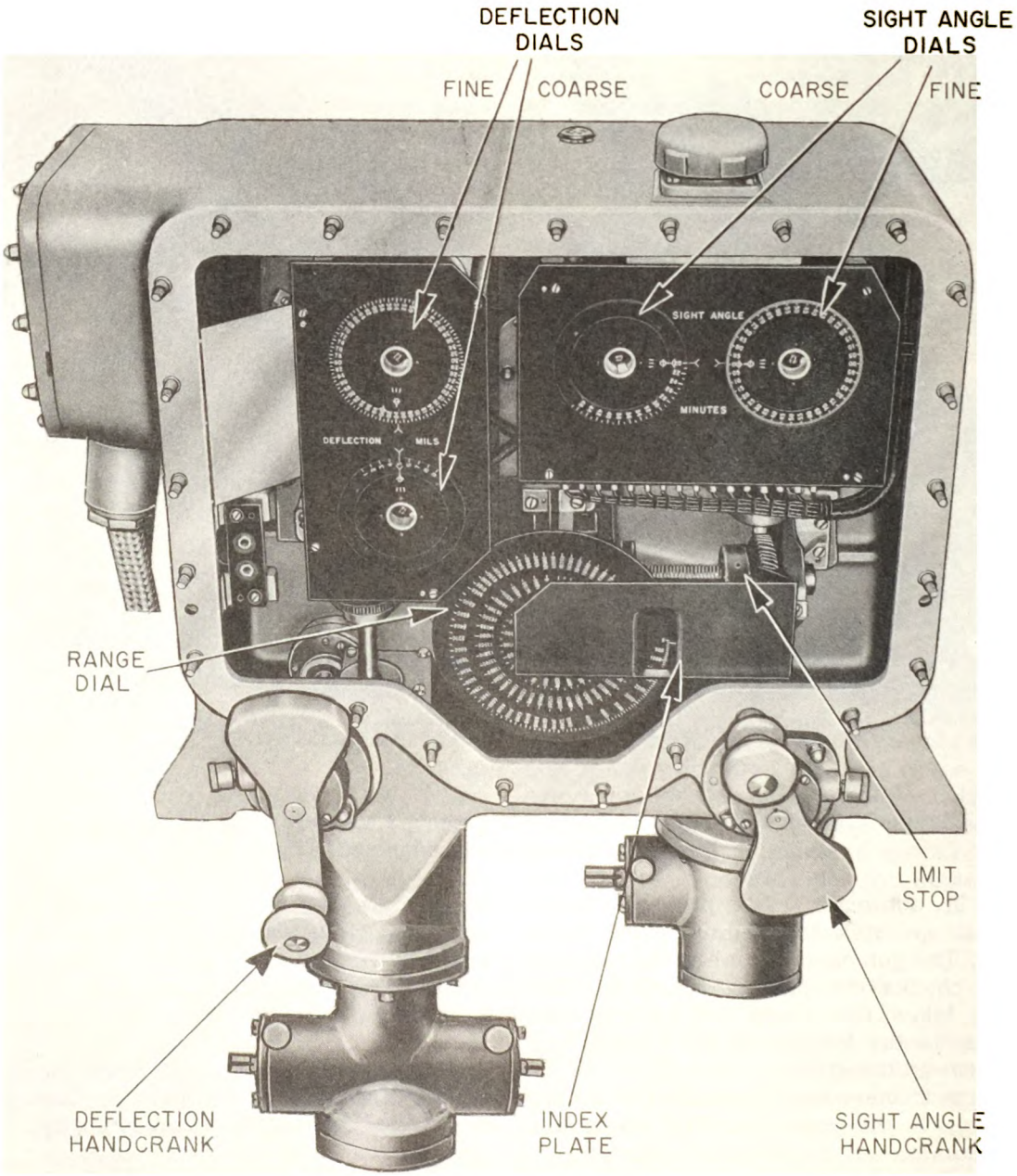

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Figure 5C9.—5''/38 twin mount. Sightsetter's indicator.

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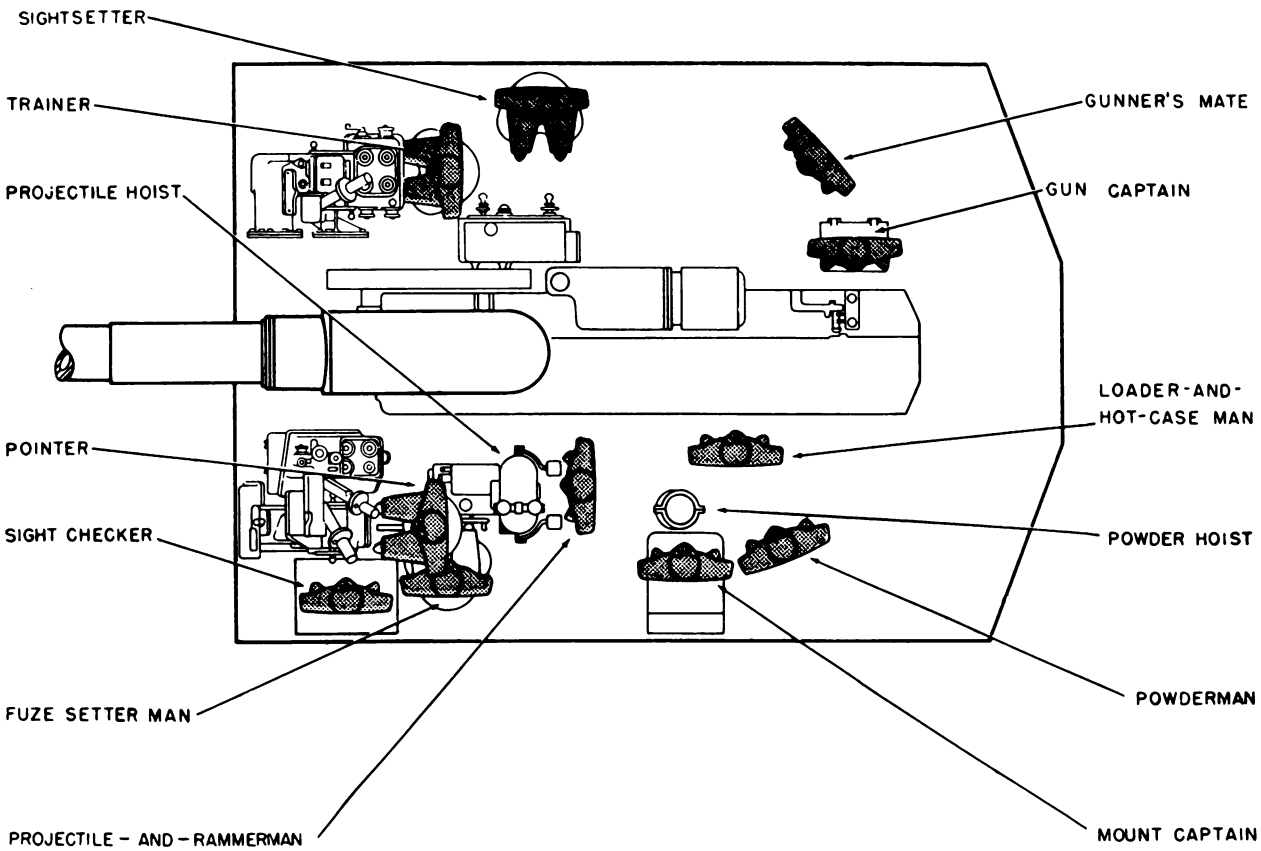

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Figure 5C10.—Mount Mk 39. Crew stations (gun house).

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D. Linear—Rate Fire Control Systems

5D1. INTRODUCTION

Gun fire control systems can be, on the basis of their fundamentals of operation, divided into two main classes—linear-rate and relative-rate, as explained earlier in this chapter. There are several marks of linear-rate systems, including two dual purpose types—the Mk 37 and the Mk 68. The main difference between these is that the Mk 68 uses an electronic analog computer, while the Mk 37 uses the Mk 1A electromechanical analog computer. This discussion will concentrate on the Mk 37 system.

The Gun Fire Control System (GFCS) Mk 37 is installed on destroyers, cruisers, carriers, and some types of large auxiliaries. It is the primary means of control of 5" mounts for both surface and AA fire. It may be used, with appropriate cross connections, to control heavy machinegun mounts, or major-caliber surface-type guns in special uses.

Use of symbols. In discussing the functioning of gun fire control systems, we shall in the remainder of this chapter frequently utilize standard Navy fire control symbols to stand for specific values that the system deals with. Part 2 of Appendix A to this text contains an alphabetical list and definitions of these symbols. Each symbol will be identified in the text at least the first time it is used.

5D2. SYSTEM FUNCTIONS AND COMPONENTS

The primary functions of the Mk 37 GFCS are to provide:

1. Continuous automatic gun positioning.
2. Continuous automatic fuze setting.
3. Continuous sight-angle and sight-deflection indication at the guns.
4. Continuous-aim, selected-level, and selected-crosslevel fire.
5. Star shell fire control.

A complete system consists of three major units: a Mk 37 director, with a radar, a Mk 6 stable element, and a Mk 1A computer, with the associated instruments at the gun. Destroyers and large auxiliaries carry one complete system. See figure 5D1. Cruisers and carriers have two systems.

Directors are installed high in the ship's structure, while stable elements and computers are installed below decks in protected plotting rooms. All elements are connected by a synchro transmission system, and are tied into this transmission system at one or more switchboards located in the plotting rooms.

Normally, each director in a multiple installation controls a designated group of guns and is connected to a designated computer. However, switching arrangements permit any director to control any or all guns and to connect to any computer.

5D3. FLOW OF INFORMATION

Figure 5D2 is a simplified schematic showing the principal interconnections of a single Gun Fire Control System Mk 37. All electrical circuits between units of the system pass through the fire control switchboard.

The director carries sight telescopes and a rangefinder and radar equipment to measure and transmit to the computer director elevation (Eb), director train (B'r), and present range (R). The control officer in the director may estimate target angle (A), target horizontal speed (Sh), and rate of climb (dH), and send these values by telephone to the computer operators. Hand-operated transmitters in the director provide electrical transmission of elevation, deflection, and range spots (i.e., observed corrections) to the computer.

The stable element receives director train (B'r) from the computer and measures level angle (L) and crosslevel angle (Zd). These values are sent mechanically to the computer. A third value, $L+\frac{Zd}{30}$, is transmitted from stable element to computer to make up an LOS stabilization signal to be transmitted to the director. Other electrical inputs to the computer include own ship course (Co) from the gyro compass and own ship speed (So) from the rodmeter or pitometer log. Lastly, computer personnel add manual inputs as required.

The computer transmits electrically to the gun mount:

1. Gun elevation order (E'g).
2. Gun train order (B'gr).
3. Sight angle (Vs).
4. Sight deflection (Ds).
5. Fuze-setting order (F).

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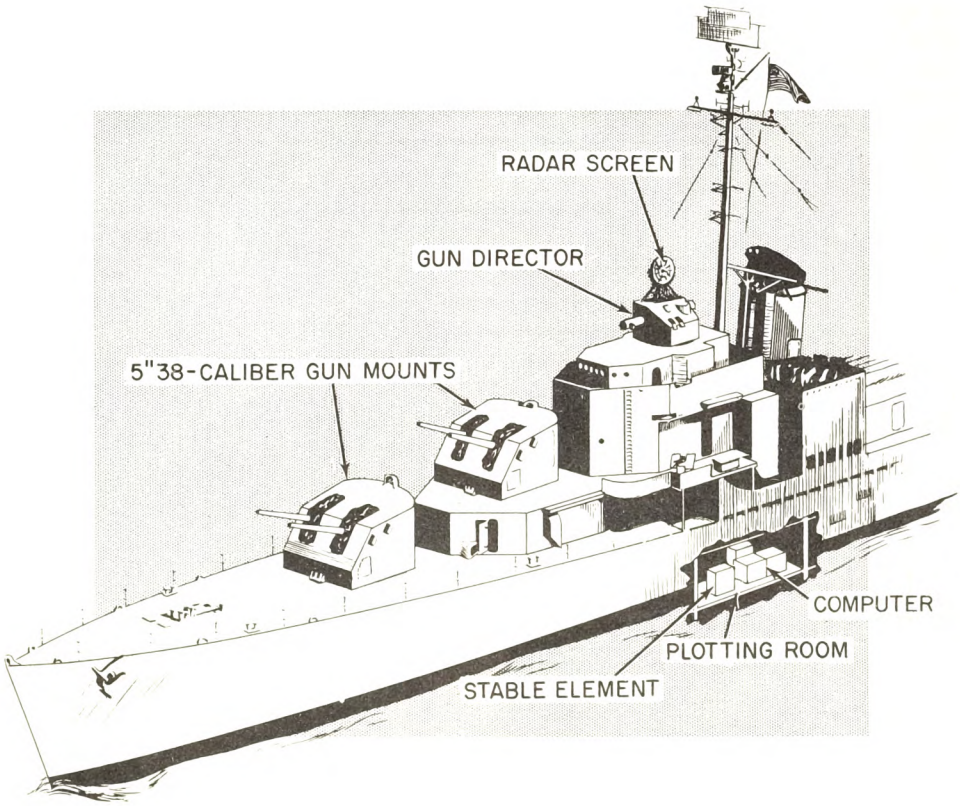

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Figure 5D1.—Mk 37 system, destroyer installation.

6. Train parallax for a 100-yard horizontal base (Ph).

These values are used for gun positioning, sight setting, and fuze setting.

In addition, the computer generates and transmits to the director changes in range, elevation, and train. With level (L) and cross-level (Zd), these changes are used to hold the director optics and radar on the target continuously. This process includes keeping the range-finder and radar on the target.

5D4. THE MK 37 DIRECTOR

Functions. The Mk 37 director is designed to control 5''/38, 5''/54, or 6''/47 dual purpose guns against either air or surface targets. Its primary function is to determine target position in terms of:

1. DIRECTOR TRAIN (B'r). The angle between the fore-and-aft axis and the vertical plane containing the line of sight, measured in the deck plane, clockwise from the bow.

2. DIRECTOR ELEVATION (Eb). The elevation of the director's line of sight above the reference plane, measured in the vertical plane containing the line of sight.

3. PRESENT RANGE (R). The distance of the target from own ship, measured in the line of sight.

Briefly, the director's secondary function is to be the control station for the entire fire control system. Normally, all units operate by remote control from the director. As long as the problem is being solved correctly, only the gun-loading crews have work to do. When changes in the problem setup are necessary, the director crew can accomplish them by remote control. To control the entire system, the director is equipped to

a. Spot service projectile fire.

b. Spot illuminating projectile (star-shell) fire

c. Correct computer calculations.

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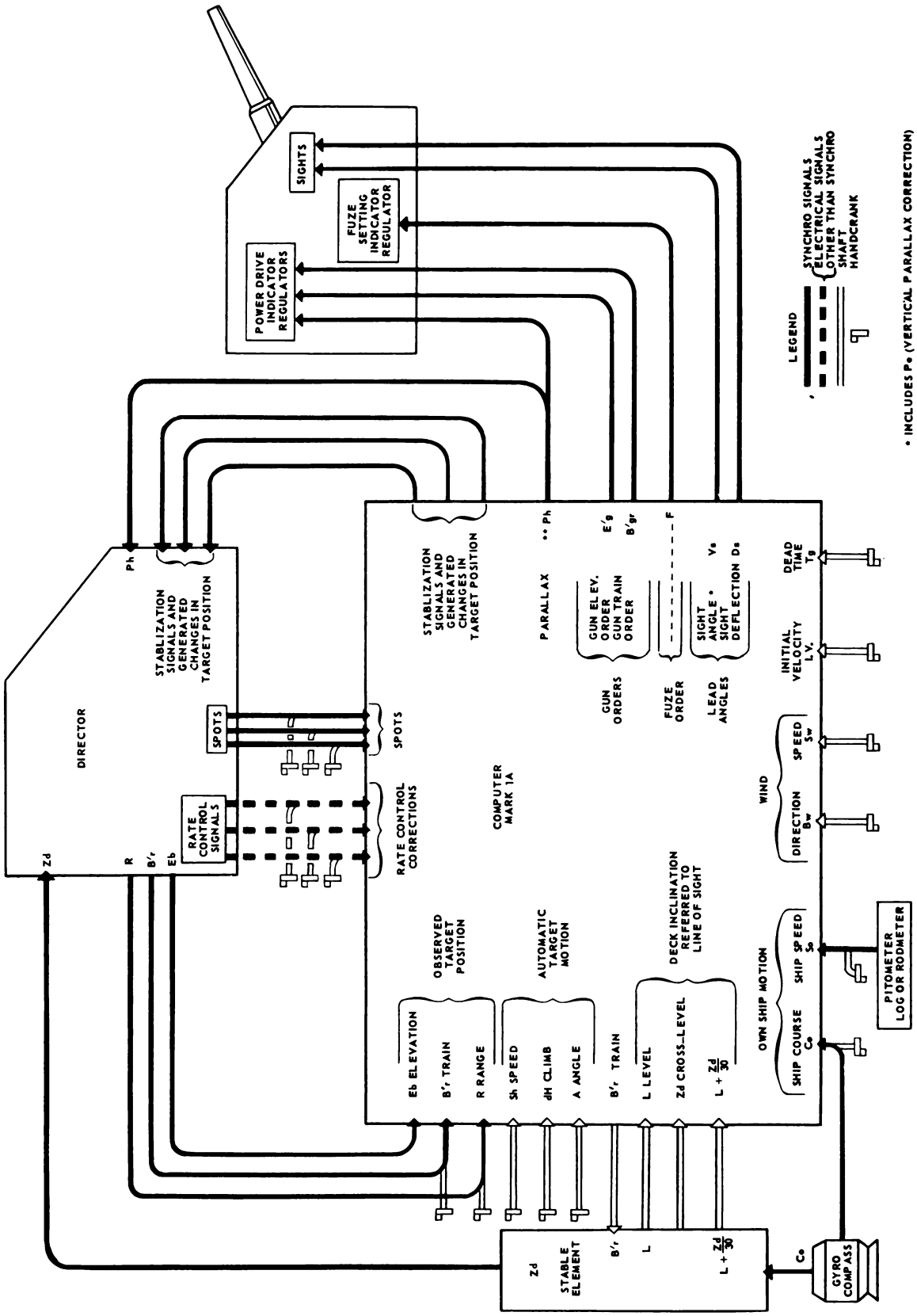

Figure 5D2.—Data flow in Mk 37 GFCS. Simplified schematic (Star shell data omitted.)

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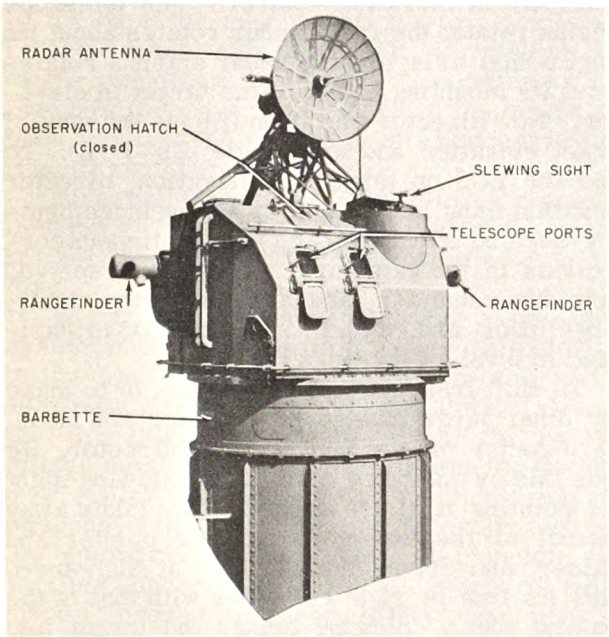

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Figure 5D3.—Gun director Mk 37.

Construction. The director (fig. 5D3) is an armored steel box that can be trained (much like a gun mount) on a precision-aligned roller path mounted on an armored cylindrical barbette built into the ship's structure. It contains an optical rangefinder and pointer's and trainer's prismatic telescopes, radar equipment, power drives for positioning the director, an observation hatch used by a control officer (who may also serve as a spotter), and a slewing sight for positioning the director to pick up the target.

General operation. The line of sight is kept on the target in train by turning the entire director on its roller path. The angle the director turns from the centerline of the ship is director train (B'r). Rotating the telescope prisms, the radar antenna and rangefinder, elevates the line of sight to give director elevation (Eb).

Train and elevation of the director line of sight can be done in four modes:

1. AUTOMATIC (or remote) control of the power drives by signals from the computer, modified as necessary by the handwheels.

2. LOCAL operation of the power drive by means of the handwheels.

3. MANUAL operation by direct gearing from the handwheels.

4. SLEWING or training and elevating rapidly to change targets.

The rangefinder determines range optically. The rangefinder operator can adjust the apparent position of the "wander marks" with relation to the target in the rangefinder field of view. This adjustment is transmitted by synchro to the computer as a range signal. The computer generates change-of-range signals that are fed back to and control rangefinder adjustment.

Radar is used for target acquisition and tracking, as explained later. It also provides for automatic tracking.

Stabilization. Director optics and radar antenna are stabilized both in level (L) and crosslevel (Zd). Stabilization in level is discussed below. Crosslevel stabilization is done by a servo controlled by a crosslevel synchro signal received directly from the stable element (fig. 5D4). The crosslevel servo motor is connected

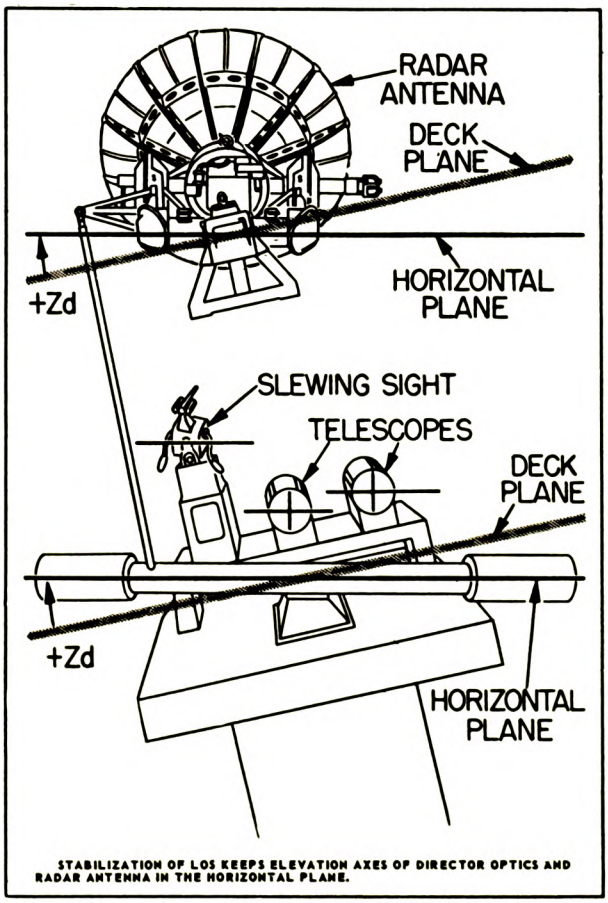

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Figure 5D4.—Crosslevel stabilization.

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to the telescopes, rangefinder, slewing sight, and radar antenna. The crosslevel drive rotates the telescopes, the whole rangefinder, and the radar antenna about the line of sight by Zd. Thus the telescope crosshairs, the rangefinder, and the radar antenna are kept horizontal, so that director elevation is measured in the vertical plane.

Train, Elevation, and Slewing Control. This discussion is chiefly concerned with automatic optical control of the director. Automatic operation, in regard to data transmission, is similar for radar and optical track; radar will be discussed later. We begin with optical train operation.

Initially, the target is acquired by slewing the director to the target by use of the slewing sight. The slewing sight can drive the director to the target at a maximum rate of speed; much faster than speed generated by the pointer and trainer handwheels. The slewsight also has a much wider field of vision than is available through the pointer and trainer optics. When the slewsight is on target, the pointer, trainer, and rangefinder operator should see the target in their optics. They then take over and provide more accurate tracking of the target. During the tracking process, B'r, Eb, and R (and any changes thereto) are automatically fed into the Mk 1A computer. Computer solution time can be shortened if the director officer telephones estimated values of A, Sh, and dH to the plotting room. But, the computer can solve the problem without these estimates, and that is most often the case. When the computer starts generating a solution, it transmits computed (generated) corrections to the director.

Computed bearing correction (ΔcB'r) consists of increments of computed change in director train, including changes in train caused by relative target motion, changes in own ship's course, and the effect of deck tilt. If ΔcB'r is correct the line of sight stays on the target without handwheel motion.

If the director while in automatic tends to drift off target, the trainer can, by closing the rate control key while he keeps the LOS on target with his handwheels, introduce a correction into the computer solution. This is necessary if there is a change in target course or speed. If the target becomes obscured, the trainer allows ΔcB'r to continue to drive the director until the target reappears.

Rate controlling can also be accomplished by the computer operators.

The description of train control applies generally in elevation control. The telescope prisms rotate; the rangefinder rotates about its longitudinal axis; and the radar antenna rotates about its mounting to follow the target in elevation. Now director elevation (Eb) is the sum of target elevation and level angle (Eb=E+L). To hold the LOS on target, in elevation, director elevation must be changed by adding increments of generated elevation (ΔcE) and continuous corrections in the value of L. These are received from the computer, and are fed to the sights, rangefinder, and radar, so that the LOS is stabilized in level as it tracks the target.

To shift from one target to another or to make any other large change in elevation and train, the director officer may slew the director. He does this by operating a key on the slewing sight and pointing it at the target. This takes away control of the director from the pointer and trainer, and drives the director at high speed until its line of sight coincides with that of the slewing sight. Slewing brings the target into the fields of the optics, and thus designates the target to the director crew.

Range control. The rangefinder's optical elements and range synchro transmitter are adjusted for range by a differential which accepts inputs both from the operator's knob and from a servo controlled by a generated range signal (ΔcR) from the computer. Thus the rangefinder operator can correct the rangefinder adjustment and transmit an accurate value of observed present range (R). He can also rate control the system by pressing a button and operating his knob, as explained in connection with train operation.

Spot transmission. The rangefinder operator has a transmitter for sending spots in range to the computer. The control officer has a transmitter with which he can send bearing and elevation spots to the computer.

Radar. The automatic tracking fire control radar has its antenna and parabolic reflector mounted atop the director, with indicator scopes and other components in the director and below decks. This radar has three types of antenna scan: spiral for target acquisition, conical for tracking, and circle for spotting shell splashes in surface fire.

Normally, the automatic tracking feature makes rate control corrections unnecessary. Tracking signals—representing target range, bearing, and elevation—are generated from radar information and compared with generated

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range, bearing, and elevation. Differences between computed and radar values are transmitted to the director as corrections, to reposition it in accordance with the radar information, and to the computer, to correct its solution until it matches the radar values. Once the target has been acquired by the radar, this process is continuous and automatic.

Director Crew. The director is normally manned by five men; a control officer, pointer, trainer, radar operator, and rangefinder operator.

The control officer is in charge of the entire system when the director is in control. In addition to his mechanical functions of accepting target designation from the designating station, slewing the director, and making spots, the control officer must originate battle orders for the battery, relay orders and information from the weapons control station, and generally oversee the operation of his battery. A complete and detailed understanding of all standard commands, procedures, and safety requisites is essential.

The pointer and trainer keep the director line of sight on target in optical tracking; they rate control as necessary. Each has a firing key that can be selected to control the firing circuit, although the pointer is most often in control. In radar tracking, the pointer and trainer cause the system to shift into full-radar track by kicking foot switches when they are on target as viewed on their radarscopes. Or, by moving their power drive handwheels and watching their radarscopes, they can keep target video positioned and thereby provide an alternate method of radar tracking. The pointer and trainer also operate special handcranks which move the director in train and elevation when searching for the target around the designated target position.

The rangefinder operator mans the rangefinder, may spot in range and deflection, and may rate control in range. When the rangefinder is not used, he assists the radar operator.

The radar operator controls the operation of the radar, supervises the pointer and trainer in their use of elevation and train radarscopes, operates the radar in range, and assists the rangefinder operator when radar is not in use.

5D5. THE Mk 1A COMPUTER

The computer Mk 1A is the mechanical brain of the GFCS Mk 37. It computes continuous gun orders containing corrections for all significant factors affecting antiaircraft and surface fire.

The gun orders, fuze-setting order, and parallax corrections are continuously transmitted from the computer to the gun mounts, where they are used to point the guns continuously, and to time fuzes so that the projectiles will explode at the predicted target position.

Construction. Computer Mk 1A is built in four sections: control section, indicator section, computer section, and corrector section. The first two are mounted on top of the second two, as shown in figure 5D5. The star shell computer, an independent unit, is mounted atop the main computer.

The control section contains the mechanisms for computing and controlling rates, and carries most of the knobs, cranks, and dials. The computer section contains the mechanisms that calculate the ballistics. The indicator section shows on dials and counters the results of ballistic calculations: sight angle (Vs), sight deflection (Ds), fuze order (F), and advance range (R2). The corrector unit computes and indicates gun train order, gun elevation order, and parallax.

Functions. The computer functions are:

1. To control continuously positioning of dual purpose guns, and setting of fuzes and sights, for either AA or surface fire.
2. To aid the director crew in keeping the LOS on target.
3. With the star shell computer, to permit part of the dual purpose battery to be set continuously for illumination of a surface target while firing other mounts at the target.

Star shell computer. The star shell computer is an independent accessory with which it is possible to direct the fire of one mount for maximum effectiveness of fire of illuminating projectiles (colloquially called "STAR SHELLS") which must be aimed and time-fuzed to burst above the target area. This computer makes such fire possible while the remainder of the battery under the control of the main computer, fires for effect.

Outputs and inputs. Figure 5D2 shows schematically the outputs and inputs of the Mk 1A computer. Note the distinction between electrical synchro signals, electrical signals (used in rate control) that are not synchro signals, mechanical inputs and outputs (between computer and stable element), and inputs manually introduced.

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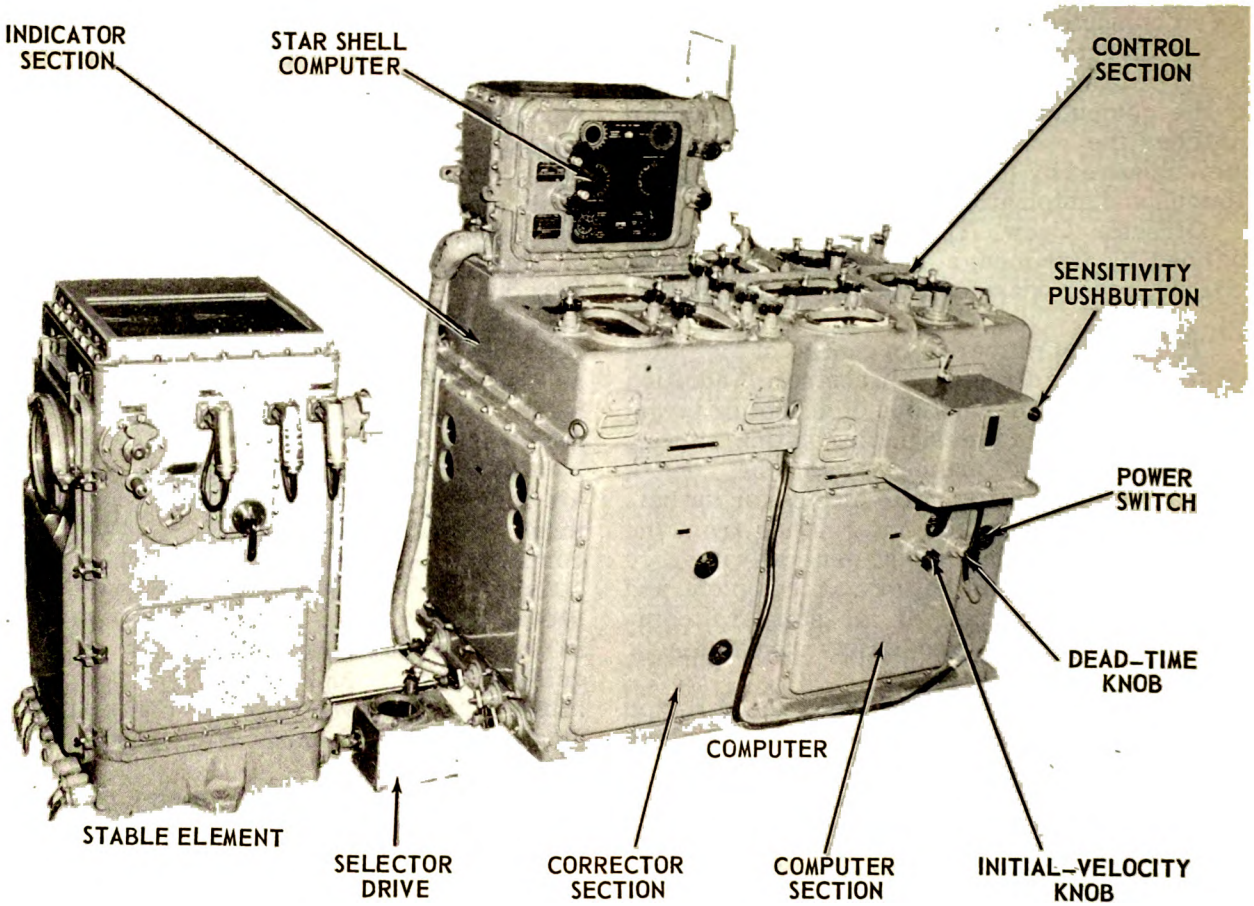

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Figure 5D5.—Mk 1A computer and Mk 6 stable element.

Computations performed and feedback effect. The computer reckons relative target motion rates which are used in generating cR, cBr, and cE (change in target range, bearing, and elevation, respectively). (Changes in Co are taken into account in computing cBr. Because rangefinder ranges are often somewhat erratic, the computer uses generated range (cR) for its calculations, to improve smoothness of operation. Measured relative target bearing (Br) and target elevation (E) are used because they can be measured accurately and smoothly. Target elevation (E) is obtained by subtracting level (L) from director elevation (Eb). (E=Eb—L.) Relative target bearing (Br) is obtained by adding deck-tilt correction (jB'r) to director train (B'r). (Br jB'r+B'r.)

The computer generates increments of range, relative bearing, and elevation (ΔcR, ΔcB'r, and ΔcE). ΔcB'r is sent to the director train receiver-regulator to move the line of sight according to the generated value of director train. It takes into account both deck-tilt correction and changes of own-ship course. Thus, if the solution is correct, Δ cB'r (known as bearing correction) will keep the line of sight on the target in train while the ship rolls, pitches, and changes course.

Δ cE is added in the computer to level correction (L) crosslevel function Zd/30. The sum (ΔcE+L+Zd/30), called elevation correction, controls the director elevation power drive to hold the LOS on target in elevation (if the computer solution is correct).

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The changes in director train and elevation from bearing and elevation corrections show up in new values of director train (B'r) and director elevation (Eb). Thus there is a continuous feedback into the computer, since the director transmits B'r and Eb continuously to the computer. The computer and director together form a regenerative system. This allows the director to follow an obscured target by riding the computer solution. As long as the solution is correct, the director will remain on the target.

Wind computations are made empirically. Air-density corrections are computed separately and applied to the computer as a change in I.V. (initial velocity). I.V. settings are otherwise based on E.S.R. data (explained in chapter 4).

The elements considered in the computation of sight angle, sight deflection, and fuze setting are:

Vs—Sight angle

1. Vt—Elevation prediction.
2. Vf—Superelevation.
3. Vw—Wind elevation correction.
4. Vfm—Initial velocity elevation correction.
5. Vx—Complementary error.
6. Pe—Elevation parallax correction.
7. Vj—Elevation spot.

Ds—Sight Deflection

1. Dt—Deflection prediction.
2. Dfs—Drift.
3. Dw—Wind deflection correction.
4. Dj—Deflection spot.

F—Fuze Setting

1. Tf—Time of flight.
2. Tg—Dead time.

The details of rate control are not discussed in this course.

Computer crew. The full operating crew for the computer consists of a range operator, a bearing operator, an elevation operator, and a star shell computer operator. In addition, a stable element operator and a switchboard operator are required for each computer-stable element combination.

5D6. THE MK 6 STABLE ELEMENT

The Mk 6 stable element (fig. 5D5) is located in the plotting room next to the Mk 1A computer. In general, its primary function is to measure level angle (L) and crosslevel angle (Zd). The stable element does this by using a gyroscope to establish true vertical and true horizontal.

The principal functional elements of the Mk 6 stable element are the sensitive element, the measuring group, the righting system, and the followup system.

Sensitive element. The sensitive element is the heart of the instrument and consists of the gyro, gyro case, gyro gimbal, and rotating fork (fig. 5D6). The gyro wheel and ball-bearing-mounted axle form the rotor of a high-speed (8500 rpm) induction motor. The gyro assembly pivots within the gyro gimbal on a case axis perpendicular to the spin axis. The gyro gimbal is supported by the arm of the rotating fork on the gimbal axis. This axis arrangement gives the gyro three degrees of freedom.

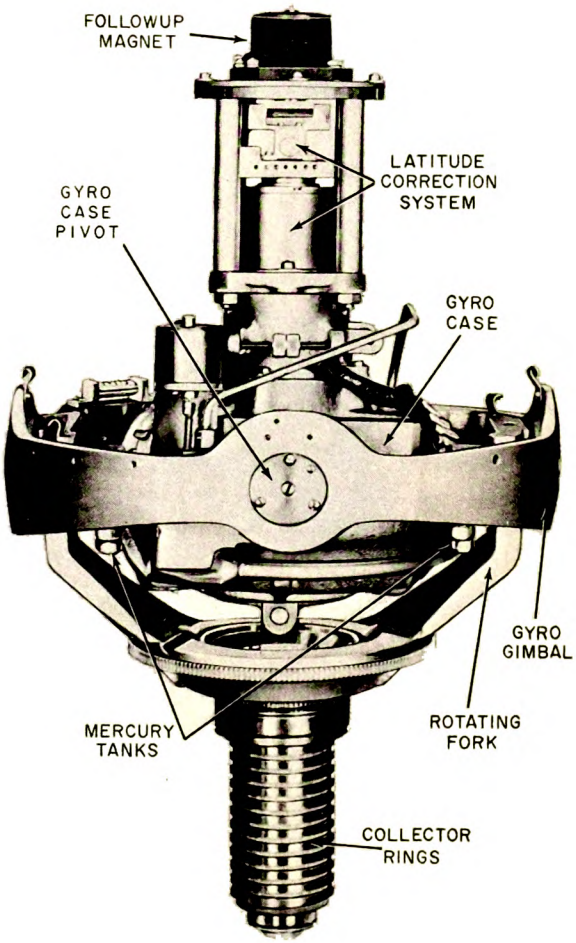

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Figure 5D6.—The Mk 6 stable element.

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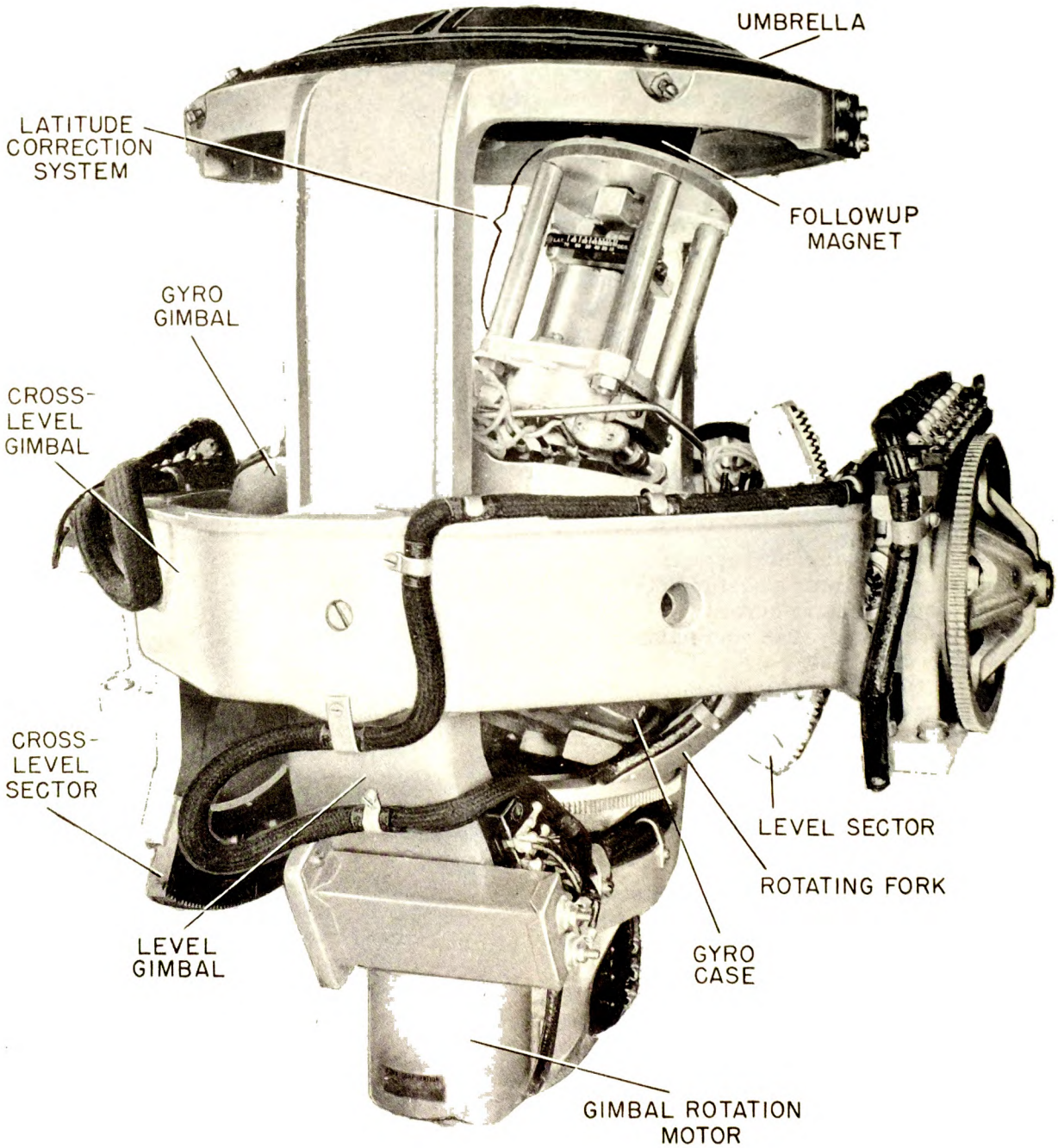

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Figure 5D7. —Complete stable element gyro assembly.

Measuring group. The measuring group consists of an inner (level) gimbal, an outer (crosslevel) gimbal, training gear, and an "umbrella" containing two pairs of followup coils, one pair for level, one for crosslevel (fig. 5D7). With this gimbal arrangement L is measured in a

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vertical plane while Zd is measured in a plane perpendicular to the deck.

Righting system. The righting system makes the gyro axis assume and maintain a true vertical position. It has two principal parts—the mercury control system and the latitude correction system (fig. 5D6).

The mercury control system consists of two interconnected tanks containing mercury, one on each side of the gyro wheel, and a gimbal rotation motor, which rotates the entire gyro assembly at 18 rpm. While the gyro wheel is horizontal, mercury level in both tanks is the same. If the wheel tilts from the horizontal, the tanks also tilt, and mercury flows at a controlled rate from the higher tank to the lower. The net effect of the mercury flow and gimbal rotation is that by the time the mercury has reached the lower tank, the tank has rotated 90° from the low point of the gyro wheel, and the pressure exerted here causes the gyro spin axis to precess back to vertical. Thus the gyro automatically erects itself when put into operation, and remains stabilized in vertical position.

Now consider the latitude correction system. Figure 5D8 depicts the effect of the earth's rotation on a free gyro. A gyro (like A in the figure) located at either pole will be unaffected by the earth's rotation. But a gyro located at the equator will, to an observer standing on the earth, appear to turn backward (westward) with respect to the earth's rotation, at the rate of one revolution every 24 hours. At any point between the pole and the equator, as the figure shows, the gyro wheel will appear to gyrate westward once every 24 hours about an axis parallel to the earth's.

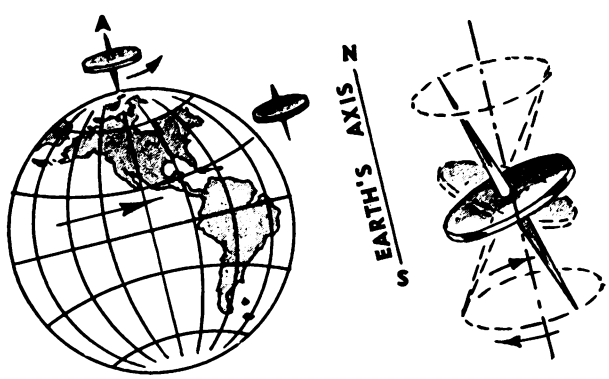

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Figure 5D8.—Effect of earth's rotation on relative position of gyro.

This effect can be compensated for by making the gyro precess slowly eastward at the same rate. The gyro's plane of rotation will then remain horizontal. To do this, a latitude weight at the north point of the gyro wheel makes it precess eastward. The position of the latitude weight is adjustable, so that it can be set for the ship's latitude. A synchro which receives Co (own ship course), B'r (director train) and other inputs keeps the latitude weight on the north point as the ship turns and the stable element trains.

Followup system. The followup system performs the actual measurement of level angle (L) and crosslevel angle (Zd). The system (figs. 5D6 and 5D7) includes the umbrella and followup coils (mentioned in connection with the measuring group), a followup a-c electromagnet on the top of the gyro case, and level and crosslevel followup (not illustrated). When the umbrella is aligned with the gyro, the followup coils put out a zero signal. When (because of ship's pitch or roll) the umbrella is not aligned with the gyro, the followup magnet induces unbalanced voltages in the followup coils. The algebraic sum of these voltages goes to an amplifier which uses the amplified signal to control rectifier tubes whose output feeds a d-c servo motor. The motor drives the umbrella until it is aligned with the gyro. Thus the umbrella "follows" the gyro spin axis. The followup units also drive synchro transmitters and operate firing switches for selected level and crosslevel fire.

E. 3"/50 Rapid—Fire Guns and Mounts

5E1. GENERAL DESCRIPTION

The 3"/50 rapid-fire (RF) guns are semiautomatic guns with automatic power-driven loaders, installed in open or enclosed twin or single mounts. They are primarily intended for air defense, but can be used against surface targets. They were planned during World War II

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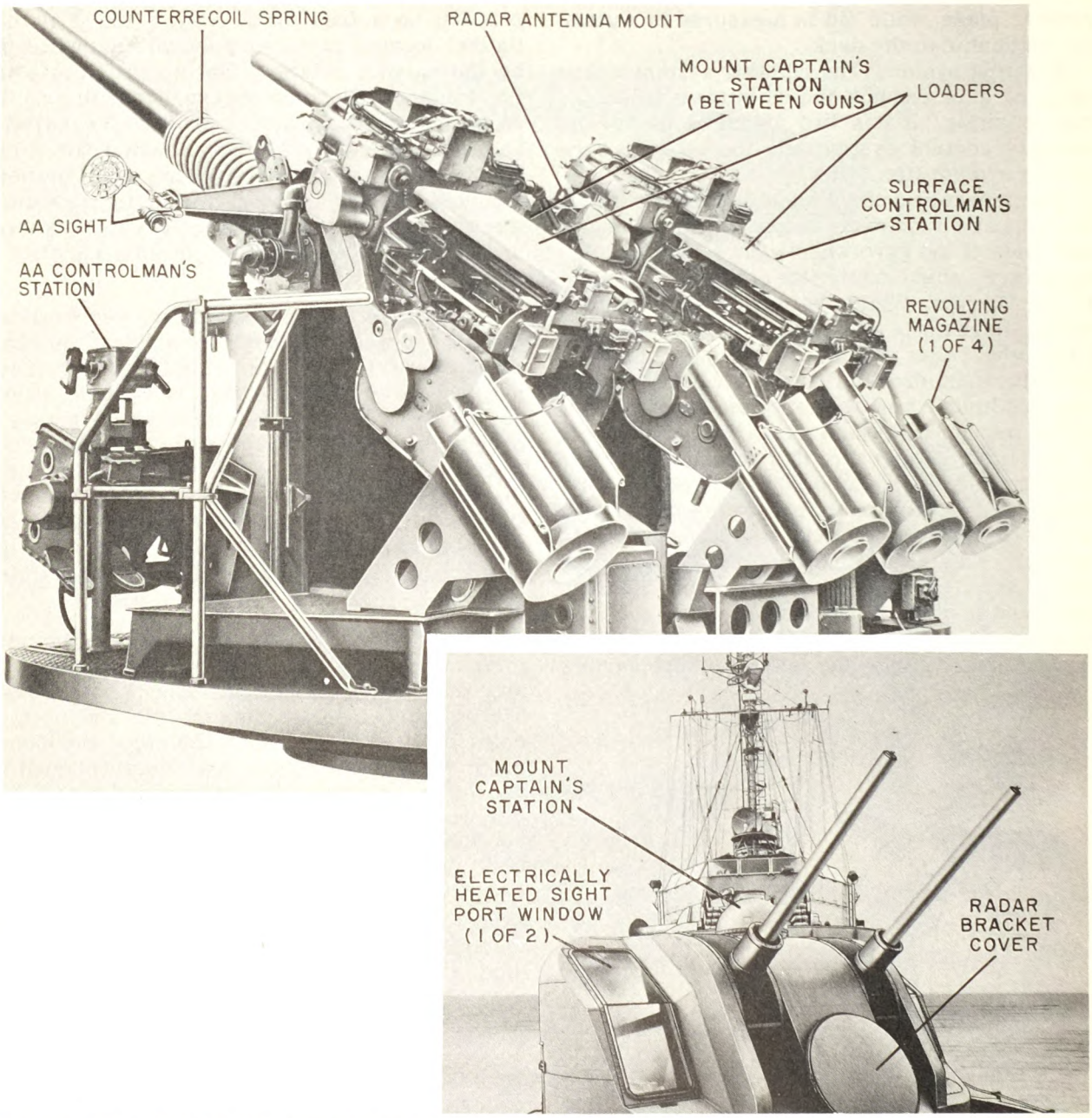

Figure 5E1.—3"/50 RF twin mount Mk 27 Mod 3. (Mk 33 is externally similar.) Inset: 3"/50 twin mount Mk 33 Mod 4. 3.122

when a need developed for a rapid-fire gun with a larger explosive-projectile that could stop suicide planes or dive bombers. The 3"/50 mount was not completed in time to be used in combat in World War II, but it has since proved itself very effective, and since World War II has virtually displaced its predecessors— 40-mm twin and quadruple mounts—on combat vessels. It is generally used with relative-rate fire control systems.

The 3"/50 rapid-fire mounts now operational in the fleet are the outwardly identical twins Mk 27 and mods and Mk 33 and mods, and the single Mk 34. All use the same gun and similar loading mechanisms (except that in the twin mount the assemblies are of opposite hand). The two marks of twins are similar in nearly all details except the slide.

Two mods of the Mk 33 are enclosed twin mounts with aluminum shield. The other mods

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are twins with modifications for installation of a fire control radar antenna, or for substitution of aluminum platforms instead of steel. The Mk 34 mount is an open single, similar in controls and equipment to the twin, with a right-hand slide and loader assembly.

General Characteristics of 3"/50 RF Mounts

Bore caliber (in.)	3.
Length (calibers)	50.
Initial velocity (fps)	2,700.
Range, horizontal (yd.)	14,200.
Range, ceiling (ft. at 85° elev)	30,400.
Design rate of fire (rds. per min)	45.
Ammunition type	Fixed, electric primed.
Fuze type	VT.
*Approximate weight, complete mount (lb):	
Mk 27	31,000.
Mk 33	31,000.
Mk 34	17,000.
Train rate (deg./sec)	3.
Elevation rate (deg./sec)	24.
Maximum elevation (deg.)	85°
Maximum train (deg.)	720°

*Not counting off-mount equipment.

5E2. CONSTRUCTION

The barrel of the 3"/50 gun is a one-piece, rifled, chambered tube, with breech end locked to the housing by a bayonet type joint. The housing contains the vertical sliding-wedge breech mechanism. The slide supports the recoiling parts (gun barrel and housing) on bearings. Recoil and counterrecoil movement are controlled by a hydraulic recoil cylinder and a large counterrecoil spring surrounding the barrel.

The slide, gun, and housing are supported by the carriage. The slide trunnions rest in roller bearings at the top of the carriage. The elevating arc on the slide meshes with the elevating pinion of the mount elevation power drive system.

The stand is a deck-flange, base-ring design which includes the training circle and the stationary roller path. In train, the mount is driven by a power motor which rotates the training pinion.

5E3. BREECH MECHANISM

In OP language, the 3"/50 breech mechanism is "an automatic vertically sliding block type which is unlocked during gun recoil action and is opened downward by gun counterrecoil energy. Its opening action extracts the empty cartridge case and sets a mechanism that holds the breech against the load of a breech closing spring. Ramming a fresh round releases these devices to automatically close the breech."

The breechblock is cammed by operating shaft rotation, as in the 5"/38. In automatic operation the breechblock is lowered and the operating spring compressed on counterrecoil when the operating-shaft crank is rotated by the operating-shaft cam plate in the slide. The breech is closed by the operating spring. The positive type salvo latch on one end of the operating shaft prevents unintentional opening of the loaded breech before the gun has fired. The breechblock houses a firing mechanism.

The general principles of sliding-wedge breech mechanism construction and operation described in chapter 4 apply to the 3"/50 gun, but two design features peculiar to the 3"/50 and therefore not taken up in chapter 4 deserve some brief but close examination. These features are:

1. A BREECHBLOCK HOLD-DOWN MECHANISM holds the breech open until the loader completes delivery of a round, and, with a novel extractor arrangement, increases the sensitivity of the breechblock-unlocking action.

2. A BREECH INTERLOCK MECHANISM prevents repetition of the loading cycle until the round has been fired and the breechblock dropped.

Breechblock hold-down mechanism. As you remember from chapter 4, ammunition is fed into the chambers of most naval guns by ramming—by a mechanically delivered push that "follows through" until the projectile is seated. In contrast, each gun on a 3"/50 mount is equipped with a mechanical loader (to be described later in this section) which catapult each round into the chamber. Since there is no follow-through, the breech mechanism must be "triggered" into closing by the momentum of the catapulted round as it is thrown forward by the loader at about 9.5 feet per second. This triggering function is performed by the hold-down mechanism, shown in figure 5E2. The hold-down lever is pivoted near its center. When the gun is in battery and the breechblock is held

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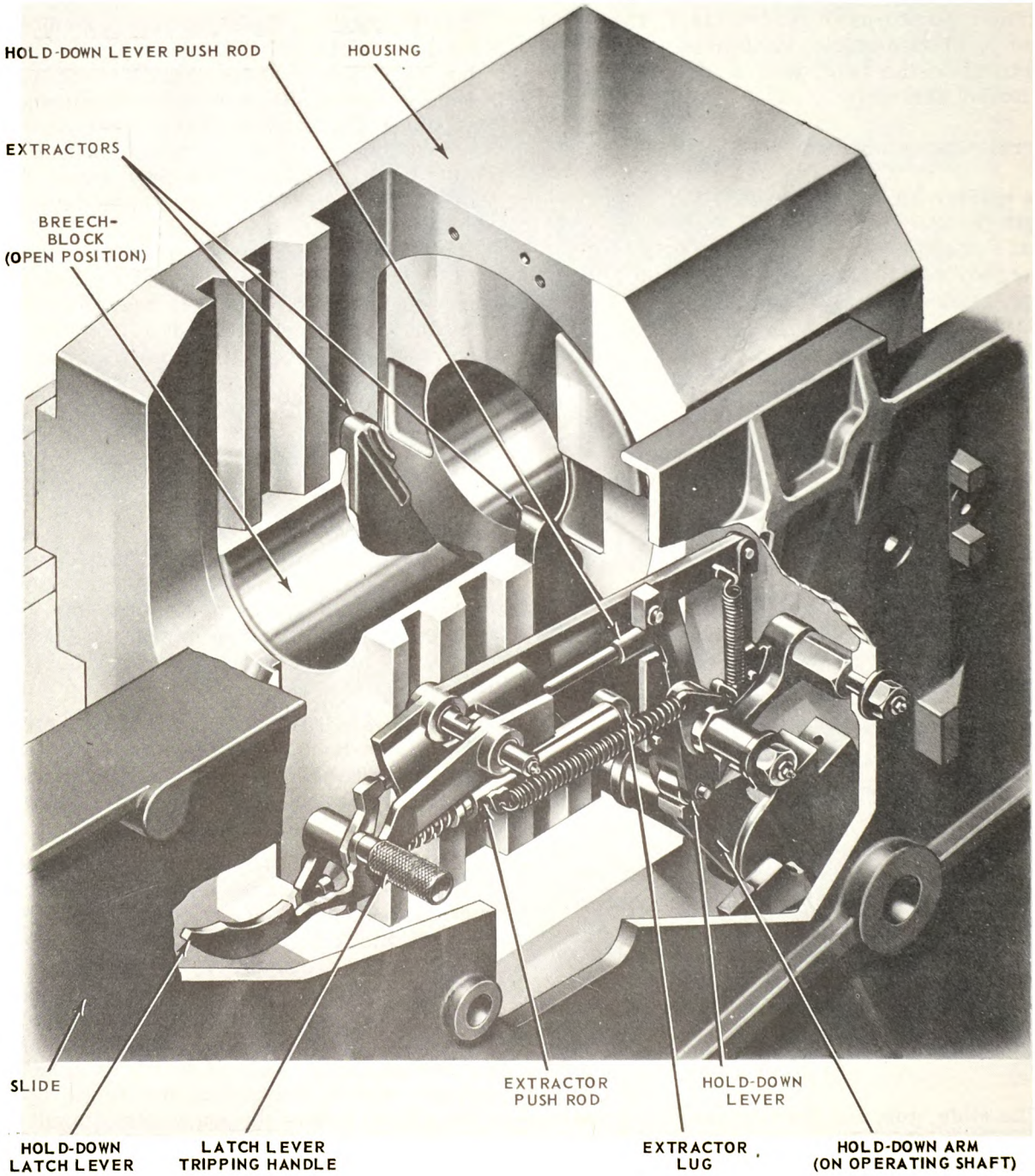

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Figure 5E2.—3"/50 rapid-fire gun. Breech mechanism and hold-down mechanism.

down, the hold-down lever bears on the hold-down arm of the breech operating shaft to prevent rotation of the shaft and closing of the breech. The hold-down latch lever interlocks the breech mechanism with the loader, unlocking the hold-down device when a new round is to be catapulted

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into the breech. The hold-down mechanism when unlocked will allow the breechblock to rise (to breechclosed position) when the rim of a catapulted cartridge case trips one of the extractors, which operates a push rod to trigger the mechanism.

Breech interlock mechanism. The breech interlock mechanism, which is technically a part of the loader, is a system of mechanical linkages which functions automatically to stop the loader from delivering another round to the breech whenever there is a round in the bore or the breechblock is up, or the gun is out of battery. When either a round is rammed or the block is raised, it actuates the loader control lever to prevent the start of a new loading cycle.

5E4. LOADER

The loader (figs. 5E1 and 5E3) is an independent, electric power-driven machine mounted on the after part of the slide. It mechanically loads each gun at the rate of 45 rounds per minute as long as ammunition is served and the firing control is operated. It is bolted to the after end of the gun slide, and is fed manually by two crewmen, who insert the fixed ammunition one round at a time into the feed sprocket on each side. (Part A of figure 5E3.) The outer sprockets alternately shift the rounds to the center sprocket, which centers the round to be loaded above a gate mechanism. When the breech is open, the gates admit the round to be loaded to a shell carriage mounted on a tray which is parallel to the gun bore axis. The loaded tray swings down on its four arms until it is aligned with the chamber, when the shell carriage, driven by an electric motor, catapults the round into the breech. (Part B, figure 5E3.) After the round clears the carriage, the tray swings upward into position to accept another round.

The breech interlock automatically blocks repetition of the loader operating cycle until the gun has fired, recoiled, and returned to battery with breech open for the next round.

All these functions are mechanically timed by control devices in the loader drive unit, and all are sequentially interlocked.

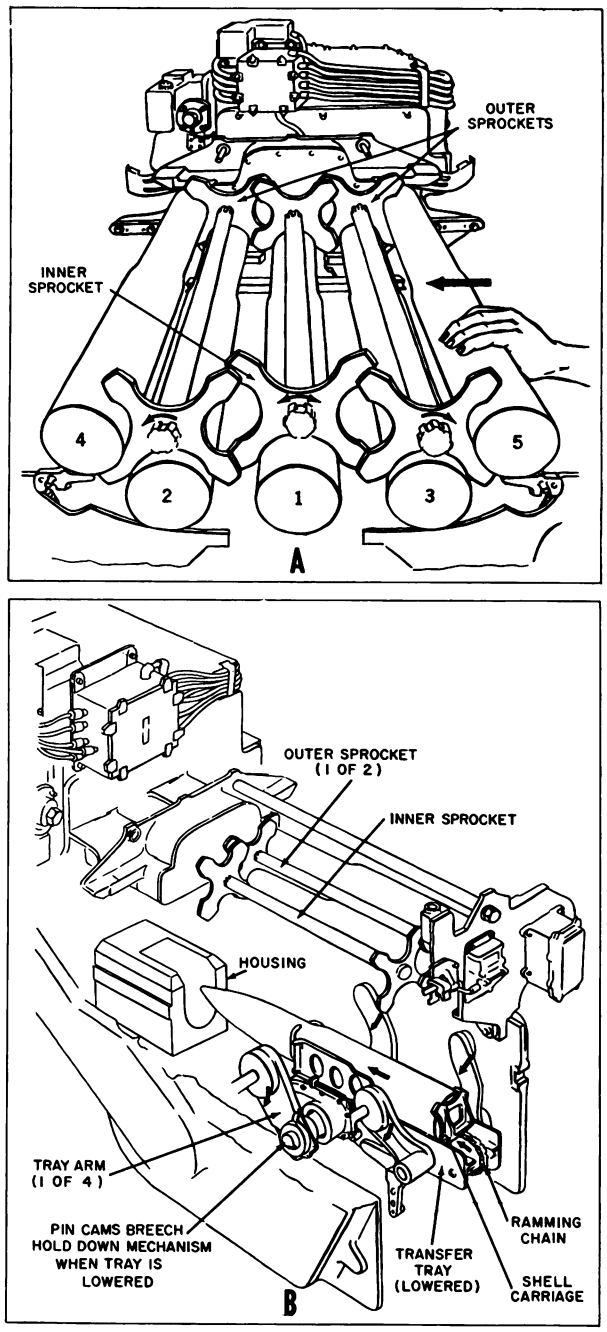

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Figure 5E3.—3"/50 loader. A. Sprockets being loaded. (Center sprocket alternates direction of rotation each cycle. Rounds numbered in sequence of loading.) B. Cartridge being catapulted into breech housing.

5E5. GUN OPERATING CYCLE

Here, briefly, are the main steps in the cycle of operation of the 3"/50 gun and loader:

1. (Figure 5E3, part A.) Crewmen load rounds into the hopper of the loader. Three

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cycles of loader operation are necessary before the loader is ready to catapult the first round of ammunition into the breech, which it does on the fourth cycle.

2. (Figure 5E3, part B.) As the tray approaches the bottom of its swing, the shell carriage moves forward to catapult the round into the gun breech. At the same time, a pin on the tray cams a lever on the breech hold-down device to unlock it.

3. As the round flies forward into the breech, the cartridge rim engages the extractors. Extractor movement releases the unlocked hold-down device (see preceding stop) and the operating spring raises the breechblock to close the breech. The breech interlock and several electrical interlocks keep the loader from recycling until the proper time.

4. As the breech closes fully, the firing pin contacts the cartridge primer much as in the 5''/38 mechanism. When the firing circuit closes, the gun fires, recoils, and counterrecoils.

5. As the gun counterrecoils, a breech opening cam on the slide engages the operating shaft crank. This rotates the breech operating shaft, pulling the breechblock down until the hold-down device locks it open. The extractors (not shown) haul the fired case out while the block goes down. The gun is now ready for the loader to catapult the next round.

5E6. MOUNT DRIVES, CONTROLS, SIGHTS, AND CREW

All 3''/50 rapid-fire mounts have amplidyne power drives for both train and elevation.

There are no provisions for manual drive, except handcrank arrangements (not illustrated) intended only for stowing and servicing the mount. But there are two types of local control—AA LOCAL and SURFACE LOCAL, plus automatic remote control from a director. Each side of the mount has a separate control station.

In AA local, the left gun layer (AA operator) controls the mount in both train and elevation, and fires the mount. The left gun layer uses a ring sight (figure 5E4, part A) and a one-man gun-laying control unit with firing key. The right gun layer's controls (part B) consist of a telescope and open sight, and a one-man gun-laying control unit with firing key. Handwheels are not used in local control for positioning the mount; the gun layers train the mount by twisting the control units about a vertical axis, and elevate

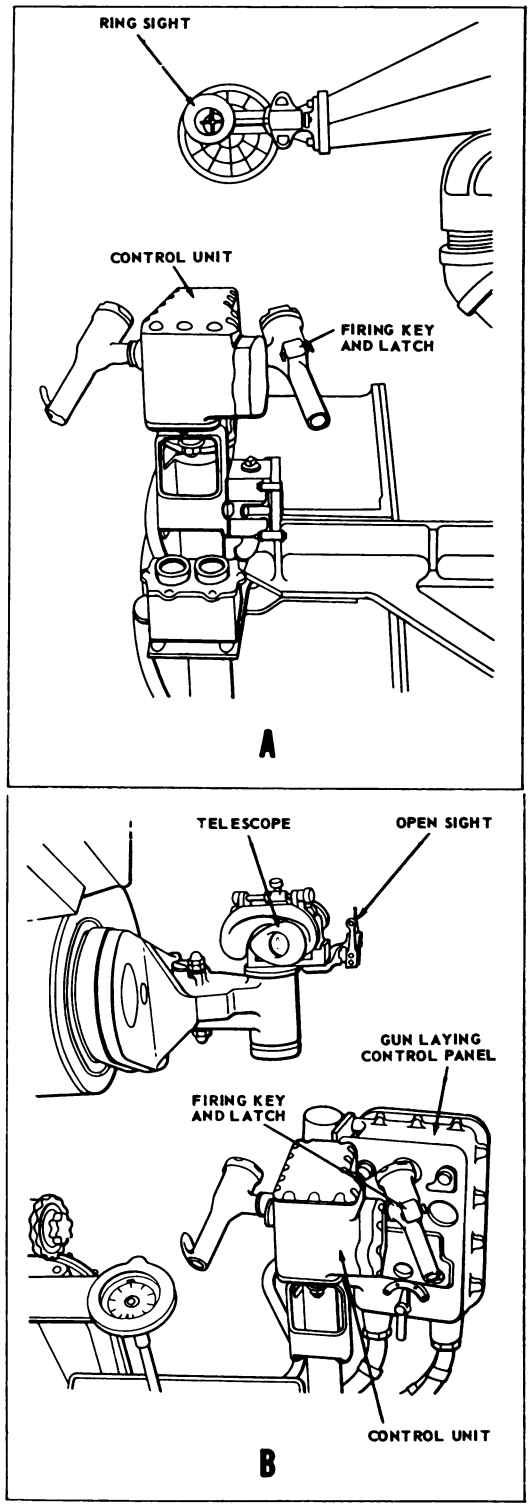

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Figure 5E4.—3''/50 mount. A. Left (AA) gun layer's station. B. Right (surface) gun layer's station.

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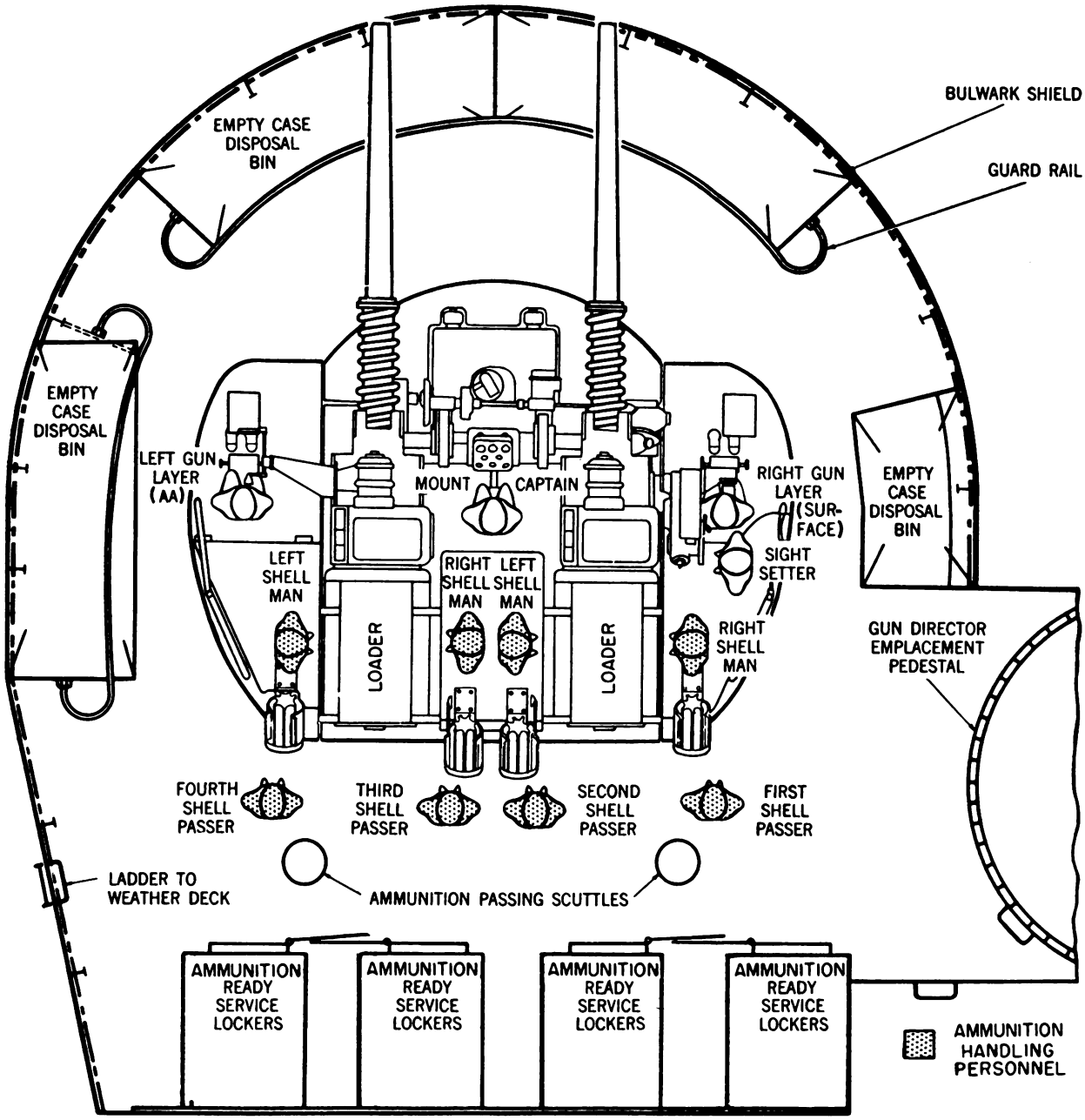

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Figure 5E5.—3"/50 rapid-fire twin mount. Crew stations.

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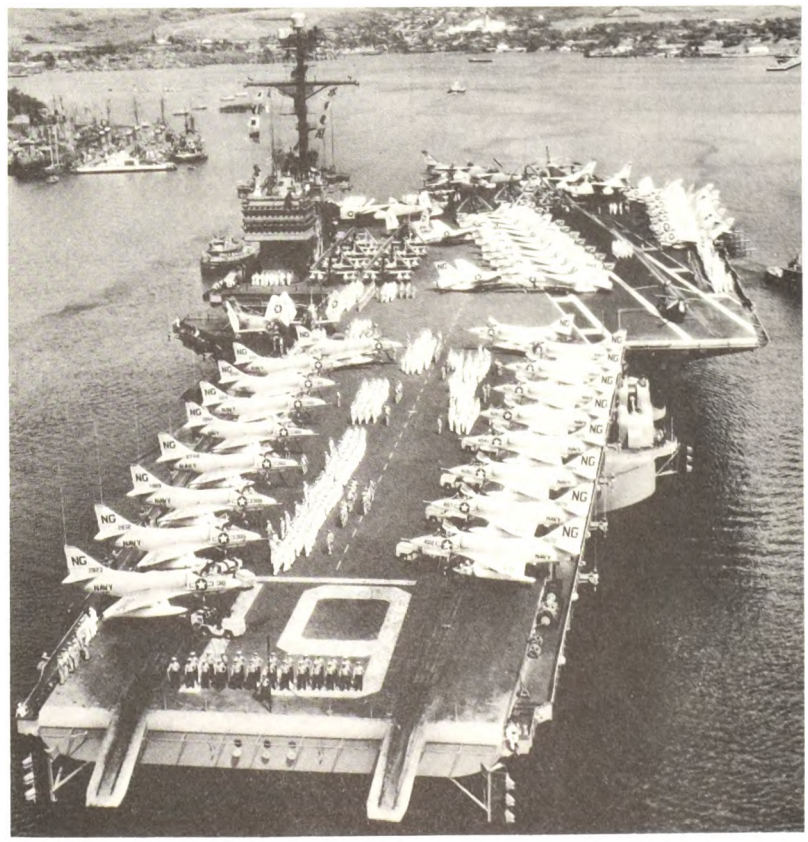
by twisting the control handles about a horizontal axis. However, automatic control (with the gun layers merely standing by) is the preferred type of control.

The surface sight is a combination open sight and telescopic unit with provision for sight setting. With the AA sight, it is mounted on a yoke astride the slide. The surface gun layer uses the open sight to get the target into the comparatively restricted field of view of the telescope. Then he shifts to the scope, adjusting mount position with his controls to keep the crosshairs on the target. A sightsetter can crank in deflection and sight angle values in accordance with telephoned orders. There are no synchros transmitting these values to the sight setting mechanism (not illustrated).

In addition to the AA and surface gun layers and sightsetter already mentioned, the 3"/50 RF mount crew includes a mount captain, four shellmen, and four shell passers (fig. 5E5). The captain is the supervising gunner and crew captain. His operations are directed by phone by the control officer. He controls both guns with the mount captain's controls. His controls allow him to select the control station, switch to single or automatic fire, select the gun or guns to fire, and control the loaders. He also has power-drive emergency stop buttons, and two banks of neon indicators to enable him to check the loader. His firing key must be closed before the loaders will function. It can be latched closed when control of fire is to be at either left or right control station or at the director.

Two shellmen for each gun load ammunition into the hoppers of the loaders. Shell passers keep the shellmen supplied.



USS Ranger (CVS 61) leaving Pearl Harbor channel.

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F. Relative—Rate Fire Control Systems

5F1. INTRODUCTION

Relative-rate fire control systems are those based on gyroscopic lead-computing sights or computing mechanisms. A number of different gun fire control systems that work on this principle are in use in the Navy at the present time. All of them are associated generally with 3"/50 and lighter guns (although some are set up to control 5-inch weapons also), in contrast to the Mk 37 and Mk 68 linear-rate systems, which are primarily associated with heavier weapons. The general characteristics and principles of relative-rate gun fire control systems (especially as compared with linear-rate systems) were discussed earlier in this chapter. This section is chiefly devoted to a somewhat more comprehensive description of one such system—the GFCS Mk 56. However, it is not intended as a fully detailed description of the system.

5F2. MK 56 GFCS: GENERAL DESCRIPTION

The Mk 56 GFCS (fig. 5F1) is an intermediate-range gun fire control system primarily designed for use against high-speed subsonic targets, but usable also against surface targets. It is most commonly used with 3-inch guns, but can control 5-inch guns also. It is a dual-ballistic system—that is, it can provide elevation, train, and fuze-setting orders simultaneously to two different batteries of different calibers. It can produce a fire control solution within two seconds after tracking begins. The system is capable of either optical or automatic radar tracking in bearing, elevation, and range, and of remote control from the control room below decks. This feature provides for rapid radar acquisition of obscured targets and for blind firing (i.e., firing without visual contact).

The system consists essentially of a two-axis, power-driven, direct-line-of-sight director located above decks, and various computing units located in a control room below decks. Complete radar equipment is included as an integral part of the system. The radar antenna is mounted on the director, and all radar indicators are in the control room (fig. 5F1).

The system is operated by a crew of four men, including the control officer. The latter and the pointer are stationed in the director for optical acquisition and the tracking of visible targets, and the two other men are at a console in the control room. On the console are all radar indicators and operational controls for handling range and positioning the director. Acquisition of obscured targets is accomplished from the console by matching designating dials.

Director line of sight (including radar antenna) is stabilized by a gyro unit in the director. Computation of lead angles is based on director angular rates of motion in stabilized coordinates.

5F3. MK 56 GFCS: GEOMETRY OF THE FIRE CONTROL PROBLEM

The fire control problem is expressed somewhat differently in the Mk 56 GFCS than in the linear-rate systems. Figure 5F2 shows the planes in which the values are expressed and the solution is developed in the director and computer. The actual solution for lead angles (but not ballistic and other factors) is performed by two gyros in the director—a rate gyro whose precession during tracking develops lead angles with respect to the LOS, and a vertical gyro which like the stable element of the Mk 37 system maintains the true horizontal and vertical reference planes.

The angular velocity of the LOS during tracking can be resolved into angular rates in two mutually perpendicular planes (fig. 5F2). One of these angular rates is elevation rate ($\underline{dE}$); the other is traverse rate ($\underline{dBs}$). The solution, however, requires the use of linear rates of target motion, in a plane perpendicular to the line of sight at target's position. This plane is called the cross-traverse plane, and contains $\underline{RdE}$ (linear elevation rate) and $\underline{RdBs}$ (linear deflection rate). Since the target is not moving entirely in the cross-traverse plane, the range changes at the rate $\underline{dR}$, measured along the line of sight. $\underline{RdE}$, $\underline{RdBs}$, and $\underline{dR}$, are the three basic linear rates of target motion.

5F4. MK 56 GFCS: SOLUTION OF THE FIRE CONTROL PROBLEM

Determining target position. The first step in the solution of the problem is determination of target position. Target bearing and elevation are measured by the director. As the target is

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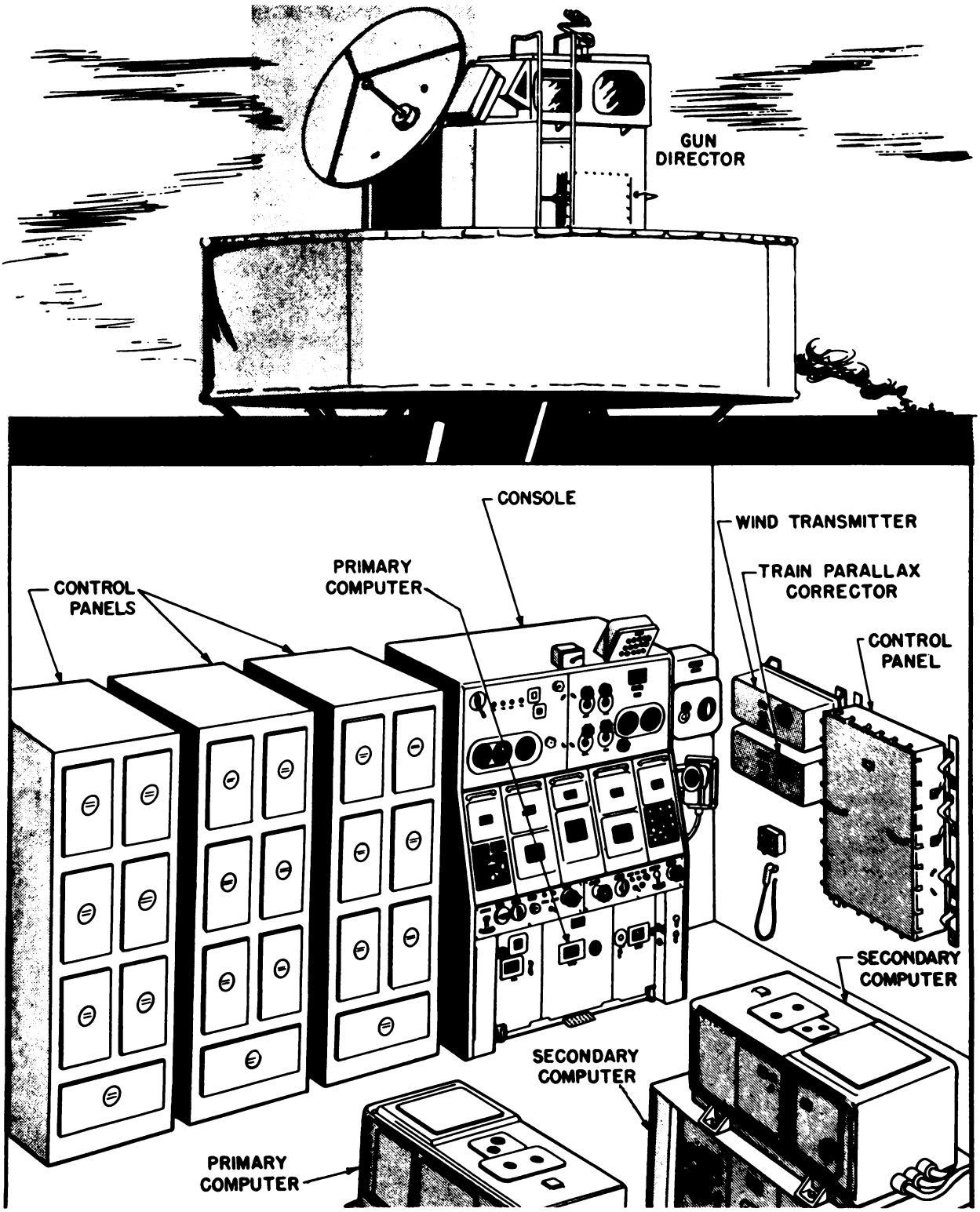

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Figure 5F1.—Components of Gun Fire Control System Mk 56.

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tracked, director train B'r' and director elevation E'b are measured and transmitted by synchros to the computer. Target range (R) is measured by radar and transmitted automatically to the computer.

Tracking the target is done either optically or by radar. A tracking control unit and a telescope on the director are used for optical tracking. In automatic radar tracking, the tracking signals originate in the radar equipment, and are accurate within one-half mil.

The primary purpose of the vertical gyro is to establish a stable reference plane called the true traverse plane (fig. 5F2). It also measures E, true elevation of the director line of sight above the horizontal, and Zs, cross-traverse angle. Like crosslevel, cross traverse is motion about the line of sight due to movement of the deck, but cross traverse is measured in the cross-traverse plane, which is perpendicular to the line of sight, and therefore differs from crosslevel. The values of E and Zs are picked off electrically and are transmitted to the computer where they are applied in calculating ballistic corrections and gun orders. Zs also goes to the cross-traverse drive gear of the rate gyro.

The rate gyro controls the drive motors, which position the director in train and elevation. It does this by measuring the angular rates of target motion in the form of electrical tracking signals and combining these signals with the stabilizing signals E and Zs from the vertical gyro. The algebraic sum of these signals is obtained in a set of pickoff coils which function somewhat like the umbrella and coil arrangement in the Mk 6 stable element discussed earlier in this chapter.

Measuring rates of target motion. The second step in fire control problem solution is measuring the rates of target motion. The preceding paragraph mentioned that as the target is tracked in elevation and train, error voltages generated in the pick-off coils go to the computer as rates of target motion (dE in elevation and dBs in traverse). As for range data, the Mk 56 director has no optical rangefinder, but range information is normally supplied by radar, or it can be cranked in manually if necessary. As radar tracks the target, changes in range (range rate) drive a tachometer generator—a generator whose output voltage is directly and accurately proportional to speed—which produces a range rate (dR) voltage signal. From these three rate signals (dE, dBs, and dR) the computer can calculate lead angles in true traverse and true elevation.

Computation. The remainder of the solution process takes place in the computer, which includes the ballistic computer, wind transmitter, parallax corrector, and gun order converter, with associated amplifiers. Computations are performed by electrical and mechanical networks distributed among these units. Any of these units or all of them together may be considered as the computer.

From present target position and the rates of target motion the computer calculates superelevation and drift. To correct for wind the computer receives by synchro own ship course from the ship gyro compass, and manually introduced values of true wind speed, true wind direction, and own ship speed. Initial velocity and dead time are also cranked in manually. Ballistic corrections are computed in terms of rates. Angular rates dE and dBs received from the director are multiplied by R to give linear rates RdE and RdBs. Then corrections to the linear rates, RdE, RdBs, and dR are worked out for superelevation, wind, etc.

Conversion to gun orders. The Mk 56 system's geometry is based on the true elevation and true traverse planes, as described earlier. But gun orders must be expressed in deck coordinates. The computer therefore converts the computed lead angles to deck coordinates. Additional computer units simultaneously convert these values to produce gun orders for another battery of different caliber.

Parallax correction. Parallax correction is in principle similar to that already described for linear-rate system, with standard horizontal correction computed on a 100-yard base and converted at each mount to the proper value. The Mk 56 system also computes vertical parallax correction.

5F5. MK 56 GFCS: SUMMARY OF SYSTEM OPERATION

Figure 5F3 shows the flow of basic quantities in the system when using automatic radar tracking (the usual method of operation). Radar receives target echoes from the antenna and transmits traverse and elevation error signal to the gyro unit as tracking signals, and to the computer as rates of target motion. Signals from the optical tracking control unit in the director may be selected in place of radar. The radar equipment transmits range and range rate to the computer during both radar and optical tracking.

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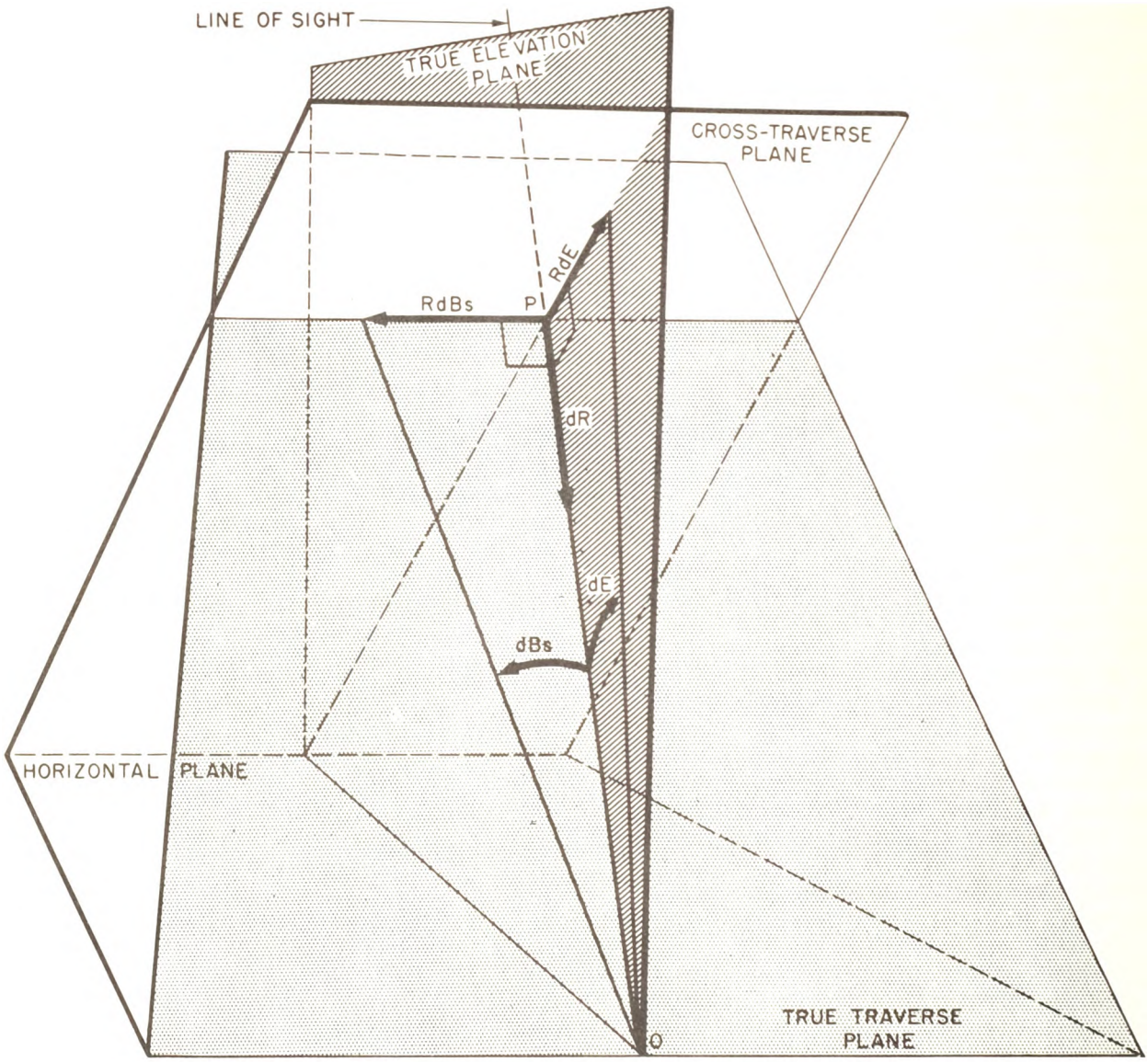

OP - PRESENT RANGE (R)
dE - INSTANTANEOUS ANGULAR ELEVATION RATE
dBs - INSTANTANEOUS ANGULAR TRAVERSE RATE
dR = INSTANTANEOUS RANGE RATE

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Figure 5F2.—Geometry of the Mk 56 GFCS statement of the fire control problem.

In the gyro unit, tracking signals are combined with stabilizing signals to control the director power drives. As the director tracks the target, director position is measured by synchros, and director train and elevation are transmitted to the computer. The gyro unit also transmits values of true director elevation and cross-traverse angle to the computer.

Own-ship course is introduced to the computer electrically, while own ship speed, true

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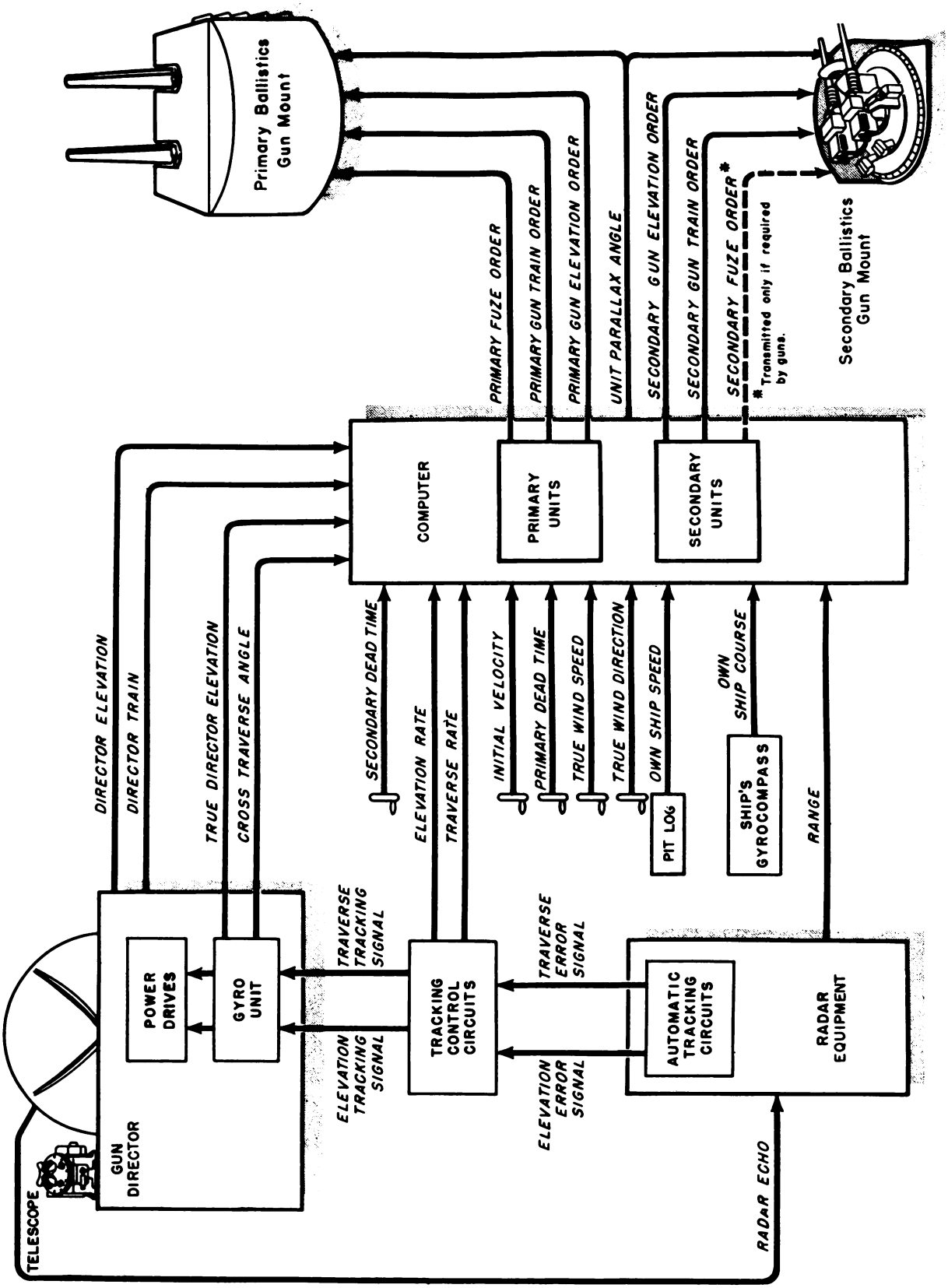

Figure 5F3.—GFCS Mk 56. Simplified data flow schematic.

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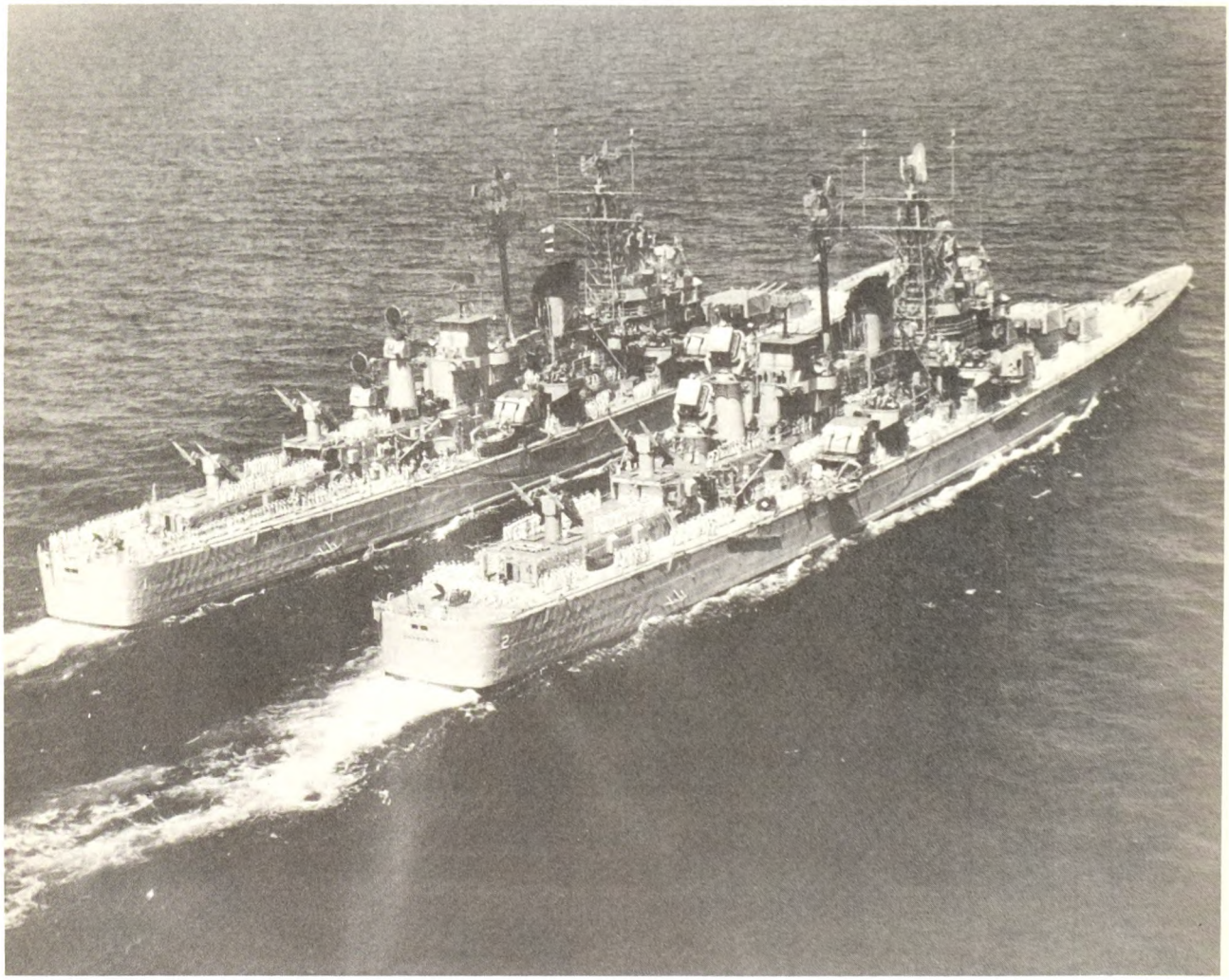
wind speed and direction, initial velocity, and dead time are introduced manually. The computer calculates lead angles and ballistic corrections. The secondary computers make up and transmit gun elevation order, gun train order, fuze time order, and unit parallax correction. Within two seconds of the start of steady tracking (either optical or radar), the computer is producing accurate gun orders.



USS Boston (CAG 1) and USS Canberra (CAG 2) off the Virginia Capes.

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G. Other Gun Weapon Systems

5G1. INTRODUCTION

This chapter has explained the fundamentals of the fire control problem and described in some detail two general types of gun weapon systems—a linear-rate system based on 5-inch gun mounts used with the Mk 37 GFCS, and a relative-rate system based on 3-inch gun mounts used with the Mk 56 GFCS. Though these systems are typical and widely used, they are not the only ones employed in the fleet. In this section we shall briefly discuss other systems (gun mounts and fire control systems) now in use in the fleet.

5G2. SURFACE SYSTEMS

Surface fire control systems are used to direct the fire of turrets. Very few of these are in the active fleet today; the main examples are the two guided missile cruisers of the Boston class, and a few other cruisers. Some of these have 8-inch turrets; the others have 6-inch turrets. The fire control systems associated with such batteries are in general similar to the Mk 37 linear-rate system. They use rangefinders instead of computers, and stable verticals instead of stable elements; from the point of view of the student of this book, these are differences in nomenclature rather than general function.

5G3. GUN MOUNTS

3"/70 mount Mk 37. The 3-inch mount Mk 37 (figure 5G1) is a twin dual purpose shield-enclosed base-ring type mount, firing fixed electric-primed ammunition. It has two 3"/70 watercooled guns mounted in a single slide. Each gun can be fired separately, or both can be used simultaneously, either in single fire or automatically in continuous bursts. Each gun has its own mechanized ammunition-handling system. Ammunition is rammed during counterrecoil, and the empty case is ejected during recoil. Critical rubbing surfaces are lubricated automatically to reduce wear. The breech mechanism is a sliding-wedge type, but the breechblock is unique (for a naval gun) because it oscillates horizontally. The prescribed crew in the mount includes the mount captain, surface gunner, right and left gun captains, and (optional) Gunner's Mate. Eleven more men are in the ammunition-handling and reloading operation, though the mount can go into operation and fire for some time without them if necessary.

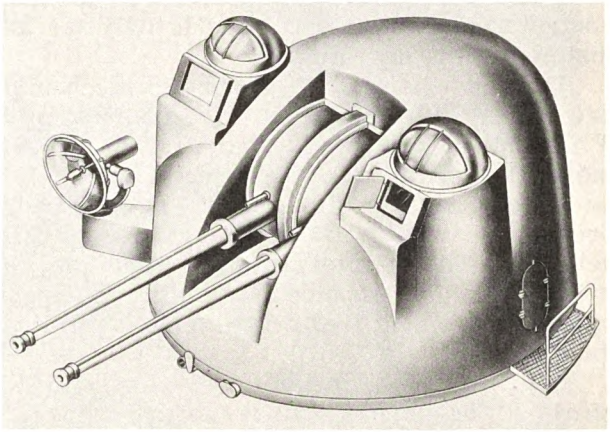

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Figure 5G1.—3"/70 Mount Mk 37. Exterior.

5"/54 mount Mk 42. The 5"/54 mount Mk 42 (figure 5G2) is a dual-purpose single enclosed mount, base-ring type, fitted with automatic ammunition feed mechanisms that permit rapid automatic fire at high speeds against air or surface targets. All mods of the Mk 42 are

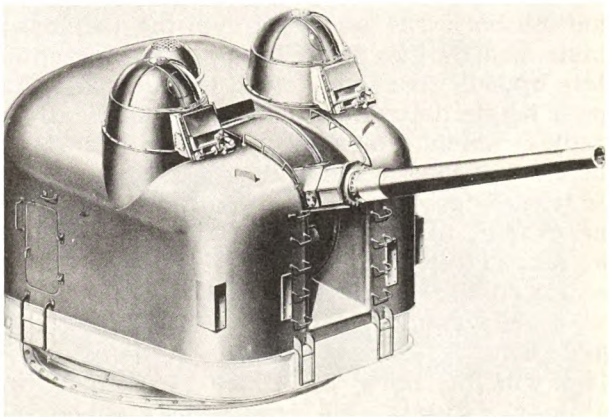

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Figure 5G2.—5"/54 Mount Mk 42. Exterior.

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fundamentally similar; the modifications adapt the mount to specific installation requirements.

Unlike the amplidyne-driven Mk 39, the 5"/54 mount Mk 42 is driven by electric-hydraulic power units. It can be operated in local or automatic control, but there is no hand control, and manual operation is only for adjustment while servicing.

The gun housing slide, and breech mechanism are quite different from the semiautomatic 5"/54 Mk 39 and 5"/38 designs. The housing moves in recoil and counterrecoil in the slide on roller bearings. The vertical sliding-wedge breechblock and the extractors are hydraulically actuated. The counterrecoil system has two cylinders on the left side of the slide; the recoil cylinders are arranged symmetrically on either side.

With its novel ammunition feed system, the single 5"/54 gun has a higher normal firing rate than a twin 5"/38 operating full blast on both barrels. In the mount's lower handling room are two cylindrical power-driven loading drums that store complete rounds of ammunition, and feed them to the two lower hoists as needed. Loading these drums is the only manual operation needed in feeding ammunition to the gun. The lower hoists automatically lift the complete semifixed rounds by stages to the ammunition carrier level (corresponding to upper handling room). A carrier (actually a power-driven frame that rotates on the hoist central column) shuttles back and forth between the two lower hoists and the two upper hoists, carrying complete rounds from the lower to the upper. The upper hoists deliver the rounds automatically to cradles which alternately swing in a vertical plane to lift the rounds to the slide. Slide transfer trays accept the ammunition alternately from one cradle, then the other. Each of the slide's two fuze setters (one on the left and the other on the right) works alternately to set the fuzes on the rounds coming in from its side. Each tray, when loaded, swings inboard on the slide to align with the bore; the round is rammed, the rammer retracts, the tray swings out of the way, and the gun fires.

5G4. LINEAR-RATE GUN FIRE CONTROL SYSTEMS

The Mk 37 system described earlier in this chapter is the prototype of two other linear-rate systems similar in function and data flow characteristics but fitted with components that are much more versatile in dealing with high-speed air targets.

Mk 67 GFCS. The Mk 67 system is similar to the Mk 37 but uses a Mk 47 electronic/electromechanical analog computer in place of the Mk 1A computer. The Mk 47 computer uses for computation purposes servos, electronic networks, and inductive devices, and a few mechanical computation devices, along with synchro transmission and computation units. The Mk 47 computer works with a mod of the Mk 6 stable element. The faster, smoother computation possible with the Mk 47 makes possible more efficient tracking of faster targets. However, this system is not designed to deal with targets traveling at supersonic speeds.

Mk 68 GFCS. This system is the same as the Mk 67, but with modifications that enable it to deal with targets traveling at supersonic speeds.

5G5. RELATIVE-RATE GUN FIRE CONTROL SYSTEMS

There are five relative-rate systems generally used throughout the fleet. They are the Mk 52, Mk 56, Mk 57, Mk 63, and the Mk 70. Of these, the Mk 56 and Mk 63 are by far the most prevalent. The Mk 56 was discussed earlier in this chapter. Since the Mk 63 and the other systems use similar operating principles and devices, we will confine our discussion here to the Mk 63.

Mk 63 GFCS. GFCS Mk 63 (fig. 5G3) is designed to control 40-mm and 3"/50 guns and is equipped to deal with air targets from 800 to 7,000 yards range, moving with speeds up to 800 knots. The major units in the system are:

1. Lead computing sight.
2. Director pedestal (on which the sight is mounted).
3. Radar equipment (with the radar antenna located on a gun mount).
4. Wind transmitter—actually a computer which works out and introduces wind correction into the system. Its inputs are own-ship course, gun train order, own-ship speed, wind direction, and wind speed.
5. Target acquisition unit (TACU). This unit aids the sight pointer in locating the target when visibility is poor or there are many targets in sight.

The director operator tracks the target manually (the director has no power drive) by training and elevating the lead computing sight on the director and keeping the target image

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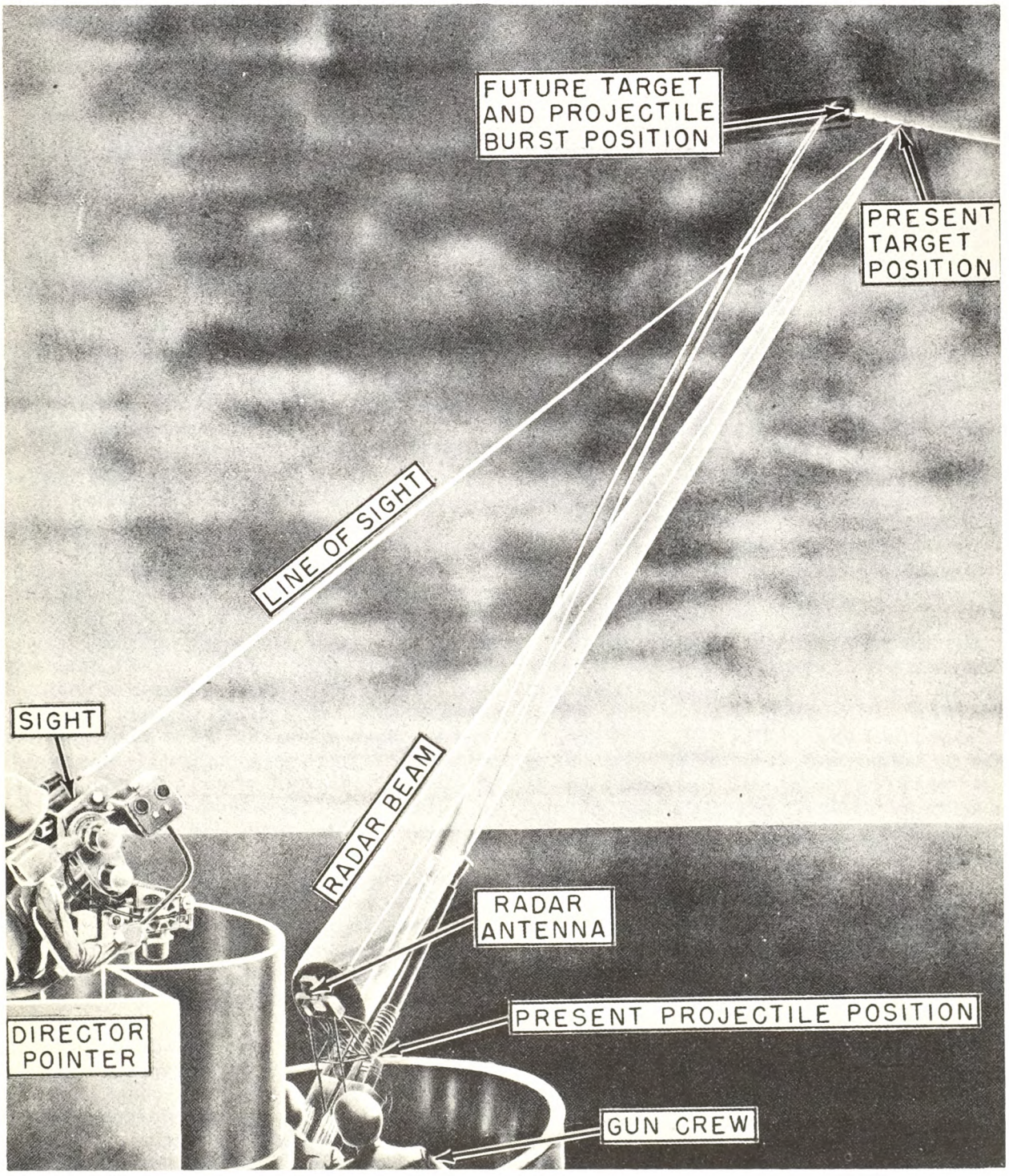

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Figure 5G3.—Mk 63 GFCS. Principle of fire control problem solution.

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centered in the reticle. The lead angle generated by the sight is transmitted to the gun mount power drive, so that the guns will lead the target. Lead angle is also transmitted to the radar antenna's independent power drive on the gun mount, but here it is applied to cause the antenna axis to lag the gun bore axis by an angle equal to the lead angle. The result of this, of course, is that the radar antenna is always aimed at the target (fig. 5G3).

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CHAPTER 6

DETECTING AND ASSIGNING AIR TARGETS

A. Introduction to Antiair Warfare

6A1. GENERAL PRINCIPLES OF AAW

Antiair warfare includes all measures designed to nullify or reduce the effectiveness of attack by hostile aircraft or guided missiles. The following broad capabilities are necessary to defeat the airborne threat.

1. Ability to eliminate the enemy threat at its base before it is airborne.
2. Ability to defend tactical units by defeating airborne attacks launched against them.

An enemy may attack with aircraft, or with missiles launched from land, from water, or from air. The trend in missiles and aircraft is for higher and higher speeds, and more distant weapon launching capability. Consequently, the time available for surface units to defend against an attack is becoming shorter and shorter. Surface units must be deployed in formations that take advantage of the defense-in-depth concept. This means (1) beginning the effort to counter the enemy attack at as great a distance as practicable from the forces to be defended, and (2) continuing this effort against the attack until it is defeated, or withdrawn.

An AAW operation may be divided into three phases occurring successively as the attacking aircraft approach the force being defended.

FIRST PHASE. The first phase includes searching for, detecting, or receiving knowledge of, and evaluating and reporting the enemy attack force.

SECOND PHASE. The second phase encompasses employment of initial active defense measures taken while the attacking aircraft are at a considerable distance from the forces to be defended. Long-range surface-to-air guided missiles (SAMs), and/or combat-air-patrol interceptor aircraft are used in this phase.

THIRD PHASE. The third or final phase is the use of AA guns, short-range guided missiles, and evasive action. During this phase the attacking aircraft are near or within the AA gun range of the main body.

Associated with these three phases is a designated AAW area; figure 6A1 is representative. Notice in the figure that three concentric circles divide the total area into a surveillance, a destruction, and a vital area. The actions taken in these areas generally adhere to the explanations of the three phases above, with the surveillance area akin to the first phase, and so on. Figure 6A1 does not describe the area diametric limits; these change depending on the nature of the expected attack. Following is a brief description of the areas:

SURVEILLANCE AREA. The surveillance area is an area in which search, detection, evaluation, and tracking are accomplished. Its outer limits are the outer limits of the AAW area.

DESTRUCTION AREA. The destruction area is the area within which destruction or defeat of the enemy airborne threat should occur. It may be subdivided into (1) an air intercept and long-range guided missile; (2) a medium-range guided missile zone; and (3) an AA gun and short-range guided missile zone.

VITAL AREA. The vital area is the area within the destruction area occupied by the forces for which defense is planned. The radius of this area is the enemy EWRR (estimated weapon release range).

Throughout this discussion of AAW, we will consider the force in question to be a fast carrier task group, controlled in AAW matter by one assigned officer. The AAW commander might not be the officer in tactical command of the task group, but he will usually be an officer of flag rank. When formations of more than one task group are involved, the AAW responsibility will most likely be split into sectors and there will be an officer in control of each.

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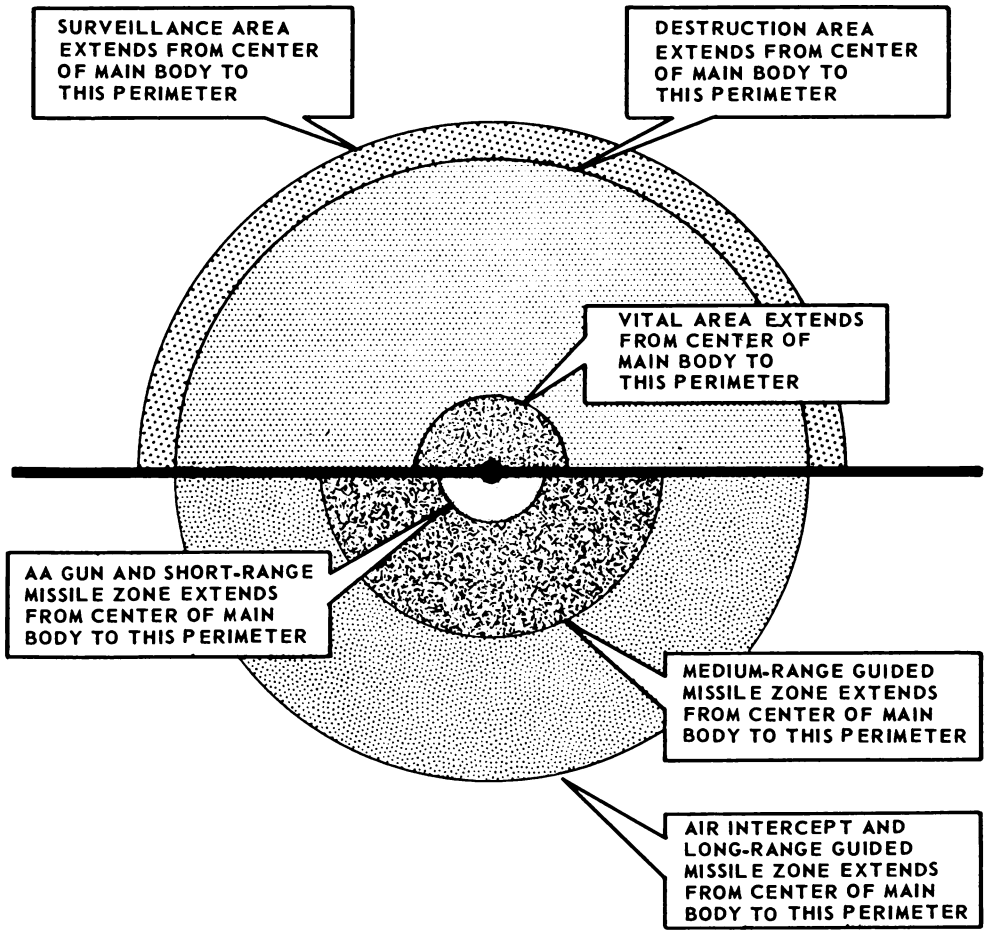

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Figure 6A1.—AAW areas.

6A2. AAW UNITS

Ships and aircraft are joined in a task group to accomplish the mission of the group. The mission is dictated by strategic necessity; its accomplishment depends on the proficiency of the group in antiair and antisubmarine warfare, and on the group's offensive striking capability. The number and type of ships and aircraft (hereafter called units) in a task group depend on the operational objectives of the group. Other groups, with similar or different objectives, are joined as needed to fulfill a mission.

An AWW formation is designed to protect an attack carrier, which is the offensive striking unit of a fast-carrier task group. The group is comprised of guided missile and conventional cruisers and destroyers, various fighter, strike, and AEW (aircraft early warning) aircraft, and the carrier itself. Submarines on radar-picket duty may also be part of the AWW formation. (An actual formation showing the locations of the AAW units may not be listed in this unclassified text.) A unit is stationed within a group so that it strengthens the defense capabilities of the group. It must be prepared to direct CAP (combat air patrol) to a target, or to use its own armament. The unit must also engage in passive AAW as regards target detection and evaluation, and transmitting target information to the AAW command ship.

Aircraft are the front line of defense; they have the speed, flexibility, and striking power necessary to engage the enemy at a considerable

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distance from the friendly force. These fighter aircraft are classified as interceptors, day fighters, and all-weather fighters. Interceptors are high-speed, short-range aircraft designed to destroy the enemy before he reaches the vital area. Day fighters are designed to engage enemy aircraft under visual flight conditions. Day fighters also perform interception and area patrol missions. All-weather fighters destroy enemy aircraft under any weather conditions. They are larger and heavier than the other fighters and have greater endurance.

Specially equipped aircraft (AEW) are used to supplement ships and submarines in providing and extending radar coverage of the air defense area, to give early warning of airborne threats, to conduct ECM search, to control fighters, and to serve as radar and communication links between pickets and the main body.

6A3. SHIPBOARD WEAPONS

Guided missiles are the second line of defense. Missiles are classified according to their effective range.

1. Short-range guided missiles have an effective range of 20,000 yards and augment the AA guns in defense of the gun zone.
2. Medium-range guided missiles have an effective range of up to 100,000 yards and engage air targets inside the first line of pickets.
3. Long-range guided missiles have an effective range greater than 100,000 yards.

For further details regarding the use and classification of guided missiles, refer to the next two volumes in this series.

Combatant ships use far more 3"/50 and 5"/38 guns for AAW than any other type.

The 3"/50 RF is a postwar (WWII) product, while the 5"/38 was widely used in World War II. A newer gun, the 3"/70, was developed and installed on DLs but there is no evidence that this gun will spread throughout the fleet. The 5"/54 (Mk 42) will, in time, replace the 5"/38; primarily because of its faster rate of fire. This does not mean that 5"/38 guns will be removed from ships, but rather that those combatant ships with 5"/38s will gradually be phased out of the fleet. At present, most newly constructed ships do not have 5"/38s, but some newly converted missile cruisers do. These guns were described in chapter 5.

Auxiliary ships and smaller craft use machineguns in addition to, or in place of, the guns described above. The three types of machinegun mounted on ships are:

1. .50 cal—on small craft.
2. 20mm—called a light machinegun in the Navy and mounted on small ships.
3. 40mm—called a heavy machinegun and mounted on small ships and larger auxiliaries.

Machineguns have a high rate of fire, short effective range, and a limited AAW capability. The 40mm has a maximum effective range (MER) of about 4000 yards, which is greater than that of the other two. 40s and 20s use impact-detonating projectiles, and a lead computing gunsight to control their fire.

Each type of AA gun has a range (its effective range) at which that gun is most effective. However, it is impossible to set this range precisely. One factor of primary importance is that the effectiveness of gunfire increases as the range decreases. Other factors are considered when establishing maximum ranges for opening fire at air targets. Although gunfire at ranges greater than effective range may result in few hits, any damage, no matter how insignificant, increases the probability of a kill and has a detrimental effect on the enemy. Opening fire beyond effective range also may effect operation of the equipment and gunnery personnel by the time the target reaches effective range.

Consequently, the maximum effective range of opening fire has been arbitrarily set as the range which will permit approximately 10-second time of flight for the projectile. The approximate MER of opening fire for presently installed AA guns is tabulated in NWP 32A.

The probability of kill on targets requiring angles of elevation above 70° is small, because of mechanical limitations of the power drive on AA guns. Therefore, high position-angle crossing targets are extremely difficult to hit. A closing air target at high altitude is also difficult to hit. As a general rule, any enemy air target above 15,000 feet will be assigned to the combat air patrol or to the missile battery for destruction.

6A4. THE AAW PLAN

Defense against an air attack demands a high degree of coordination between widely dispersed units in the formation. The attackers can climb to very high altitudes, or they can come in just over the wave tops. No matter what their altitude, their speed in many cases is supersonic. This means that instantaneous reactions and quickly computed solutions are absolutely essential to the defenders. Even after attaining

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maximum proficiency, a ship's individual efforts would probably prove futile unless she were deployed in a defense-in-depth formation. Defense in depth requires intensive coordination. Teamwork is then the order of the day and the captain of the team is the AAW commander.

The AAW commander and his staff are usually embarked in a missile cruiser where the entire AAW picture is presented on various display plots. He maintains communications, except during some conditions of electronic silence, with all of the AAW units. He receives all "bogey" (unfriendly air contact) information from the detecting ship or aircraft.

All units on the AAW radio network hear an initial contact report as it comes over in GEOREF (geographical reference) coordinates. In task groups having NTDS (Navy Tactical Data System), bogey data is promulgated almost automatically by a computer/teletype link between the AAW units. The sophisticated NTDS is beyond the scope of this text.

GEOREF plotting is done in the combat information center of each unit to locate the contact relative to the position of the unit. GEOREF plotting is covered later in more detail.

When a unit detects and reports a contact, it also makes a preliminary calculation to the contact's course, speed, and altitude. The AAW commander has time to ponder defensive actions if the target is outside the estimated weapon release point. This time is spent in evaluating the target. Does his course and speed show him to be a definite threat to the task group? Has he maintained course, speed, and altitude? Has he been confirmed as an enemy? Will he make a high-level atomic attack, or a low-level strafing run? Or, is he perhaps a diversion to draw attention from a larger attacking force?

If the bogey does pose a definite threat, the AAW commander must decide which weapon in the defense arsenal will be used. Our first line of defense is the Combat Air Patrol, CAP consists of carrier-based aircraft that patrol assigned sectors above the task group. If CAP is in the target area, and if the relative speeds show an intercept to be possible, the AAW commander may order CAP to be vectored to the target. Vectoring is accomplished by an air controller in the AAW unit that has been given CAP control. The intercepting aircraft may be able to visually identify the target, thereby confirming its belligerent status.

We can miss with CAP just as we can miss with the guns or missiles. CAP may be out of position, the relative speeds may be so great that the attacker might slip by, and conditions of poor visibility or poor radar reception during the terminal phase of the intercept might render CAP useless. Now comes our second line of defense, the surface-to-air missile.

Many things were happening on the missile ship while the CAP intercept was attempted. Extremely accurate fire control radars were being designated (directed) to the target by an elaborate weapon direction system. The direction system sent continuous target information in three coordinates (range, bearing, and elevation) to the fire control directors in the gun and missile systems. The directors then "locked on" (shifted to automatic radar track) and became electronically independent of the weapon direction system. A computer solution started generating simultaneously with director lock-on in each fire control system. The computers solved the fire control problem and computed the required launcher, missile, and gun orders.

When a ship is ready to engage the target with missiles, it reports this fact to the AAW commander. Upon receipt of more than one such report, the commander decides which ship is to take the target under fire. He considers which ship is in the best position for a kill, and the type and number of missiles remaining on board. If the target is not destroyed after multiple missile salvos have been fired, reliance must be placed upon the last line of defense—conventional gunfire.

Conventional guns are still very much a part of the Navy's armament and they continue to be effective in AAW as indicated by target practice results against high speed jet targets. Gunfire can also disrupt an otherwise orderly mass attack. A gun is not invalidated by a target's speed, but it is seriously limited when the target's RELATIVE MOVEMENT in bearing, elevation, and range exceeds the designed limits of the gun fire control system.

6A5. STEPS IN THE SHIP'S DEFENSE PROCESS

The preceding article showed how units are integrated to protect the task group's vital area. But the plan of action for any one unit is necessarily more precise; its broad outline neatly dovetails into the overall AAW plan. In order of occurrence, a ship must detect, display, evaluate, disseminate target information (within the ship), and destroy air targets. If a ship is the

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first unit in the formation to detect a target, most of its internal steps become steps in the AAW sequence for the task group. Detection, evaluation, dissemination within the task group, and (possibly) destruction of the target become one and the same for the detecting ship and the task group. Other ships will participate in destruction or evaluation if directed or needed, respectively; but they will all use the same internal sequence as outlined above. Note that displaying and disseminating within a ship are always internal steps. Following is a description of the internal steps:

1. Detecting. Detecting the target is the first and probably the most difficult part of the problem. We have devoted the next section in this chapter to detecting. Air search radars (of various designs) are the primary detecting means, but surface search radars very often detect low flying aircraft. Two other detecting methods are visual, and passive with ECM (electronic countermeasure) equipment.

2. Displaying. Target data are displayed in the CIC (combat information center) of each ship. There are three main display boards, which are called phase 1, phase 2, and phase 3 summary plots. Phases 1, 2, and 3 stand for long, intermediate, and short range respectively; or, if you prefer, the first, second, and third phases of the AAW problem. Don't confuse these phases with those previously mentioned, because these are relative to a single ship; not to the vital area of the task group. For example, an outer perimeter ship may be in its phase 3, while units in the vital area are in phase 1 or phase 2.

Figure 6A2 shows a phase 1 plot. Each small square has sides which are equal to 60 nautical miles. Since there are 100 small squares, the square mile area covered by the plot is 360,000. GEOREF coordinate identifying letters are inscribed on the edges of the board, and grid lines connect the coordinates vertically and horizontally to "checker" the board. The resulting GEOREF squares make it possible to fix a contact's position in much the same manner as a city is located on a standard road map. You will see later how numbers are used to fix the position within a square.

The main purpose of the phase 1 board is to provide a long range look at the situation. All unidentified air contacts beyond 100 miles from a ship are plotted here. Also plotted is the whereabouts of the formation center. Flagship B in figure 6A2 is the formation center of the four-ship task group shown (ships B, C, S, and T). Notice that certain intelligence items are plotted. Even though the Southeastern United States and the grid lines are drawn approximately to scale, the letters used here are not the actual letters for that locale. Bogey C-8 was detected by ship C at 2018 local time and lost after time 2023—it was then said to be in a "fade" (depicted by the wavy line). Ship T picked up bogey T-3 and made continuous reports to the formation.

Locate ship S. Notice that it is within a small square that has GEOREF coordinates of JM. (The longitudinal coordinate is always given first.) Ship S is a little northwest of center in the JM square and exactly in the center of a larger square which is shown by the broken lines. The broken-line square represents the area that will be covered by the phase 2 plot on board ship S. The phase 1 plot is also the one on board ship S. Now shift to figure 6A3, the phase 2 plot.

Ship S is in the center of the plotting board and northwest of center in the JM square. Bogey T-3 is making an attack from the southeast and his position in the KL square is the same as that which he occupied in the phase 1 plot. The physical dimensions of the squares on the phase 2 plot have been enlarged but the geographical area they represent remains the same. Now there is a quick and convenient way of relating bogey T-3 to ship S. He bears 135 degrees true at about 90 miles. Knowing the approximate bearing and range enables ship S to make an intensified search in the area with her own air search radars.

The phase 2 plot shows the surface units of the formation plus all friendly aircraft (AEW and CAP) within its radius. This plot differs from phase 1 in that the center of the plot is made to represent the geographical position of the ship (ship S in this case). The grid coordinates are adjusted periodically as the ship moves over the ground. Unlike the grid lines that are inscribed on the phase 1 board, these are wires which are attached to rods that border the board. It is a simple matter for a Radarman to adjust the wires and change the grid letters to make the center of the board correspond to the approximate position of the ship. He gets his "posit" information from the DRT which has been set to agree with the ship's radar, loran, or navigational fixes.

The phase 3 plot is an enlargement of the close-in area of the phase 2 plot. Unidentified air contacts within a 50 mile radius are displayed here. The phase 3 plot is important in

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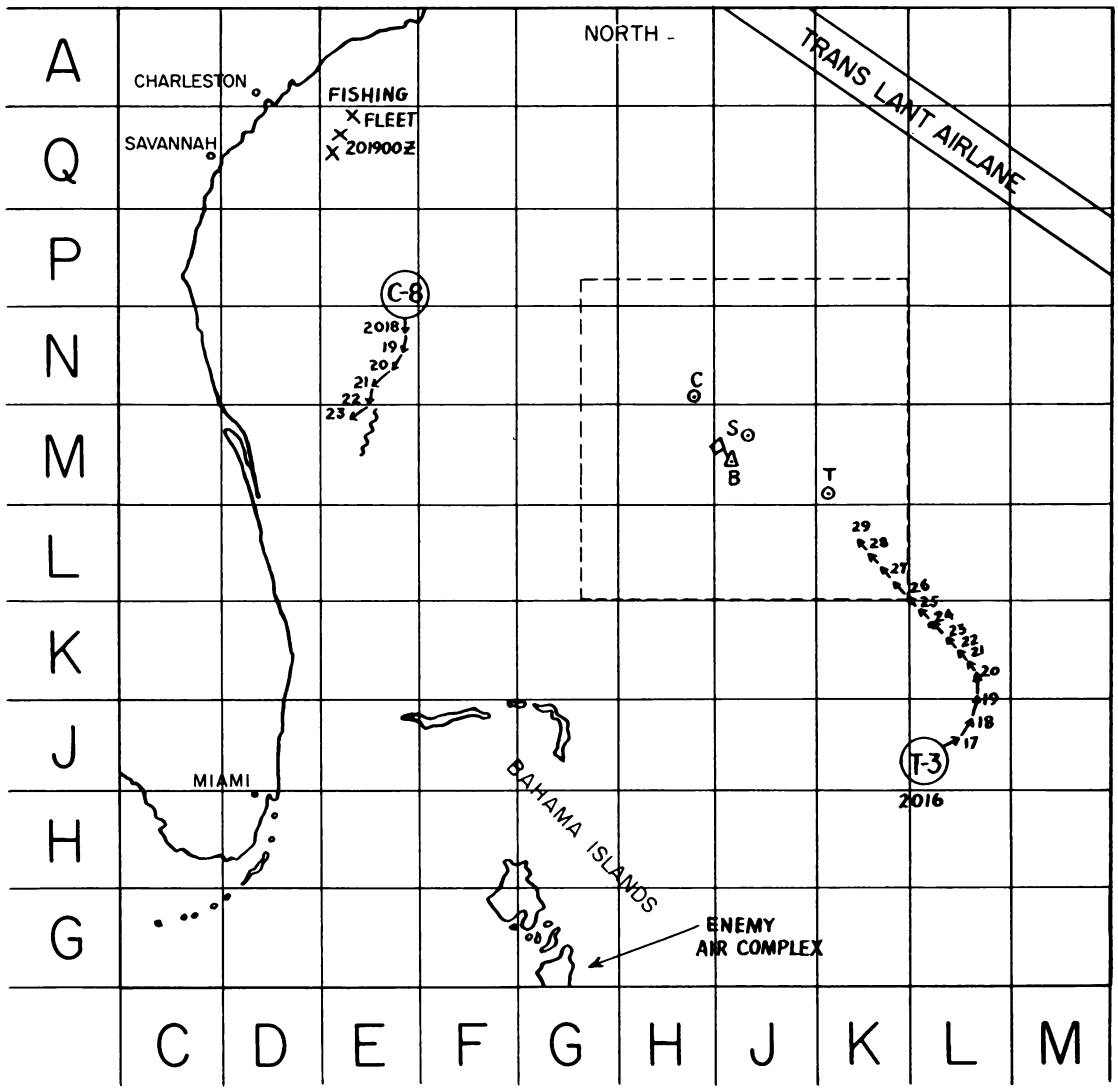

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Figure 6A2.—Phase 1 plot.

ships that do not have a long range target acquisition capability.

Figure 6A4 shows how to fix a target's position within a GEOREF square. The square is divided into equal increments in both latitude and longitude. Bogey T-3 would be reported as KL 23. The numbers shown in the figure are not inscribed on the plotting board or on the grid wires. It is useless to scribe wires that can move with respect to one another. The Radarman who is reporting the bogey's position merely estimates the divisions of the square. Other numbering systems which have about five increments are used, but the principle remains the same.

Finally, GEOREF posits are not "right on the nose." Inaccuracies stem from reporting delays and from grid wires that have been incorrectly set. Moreover, the actual position within a square is an estimate by the person reporting the contact.

3. Evaluating. The process of evaluating is continuous from the moment of detection to the subsequent intercept of the target. The

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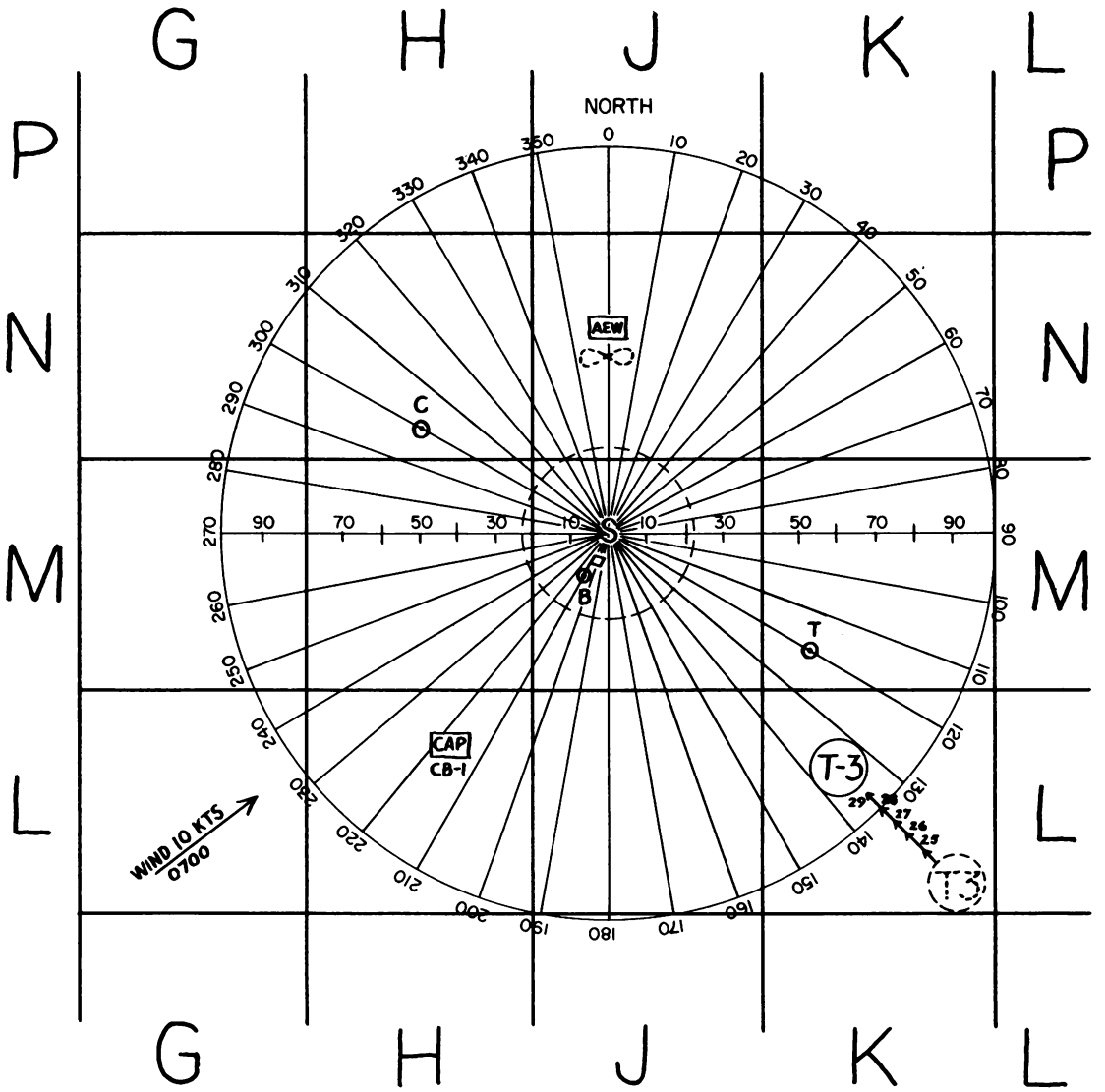

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Figure 6A3.—Phase 2 plot.

tools used most often are the target's relative position, his course, speed, and altitude, and his response to an IFF (identification friend or foe) challenge.

As we have seen, a contact may first appear on our display as a GEOREF report from another AAW unit. Included in this report will be a calculation of the contact's course, speed, and altitude. This information is sometimes hastily computed because of the need for immediate dissemination to the other units in the task group. Initial minor inaccuracies will be noted quite often when compared to the subsequent reports from that same reporting unit.

The mere mention of a contact on the reporting net indicates that the reporting unit is unable to receive the correct IFF response. It is quite possible that the IFF equipment may be functioning improperly. The only reasonable recourse in the event of no IFF return would be to get as many AAW units as possible on

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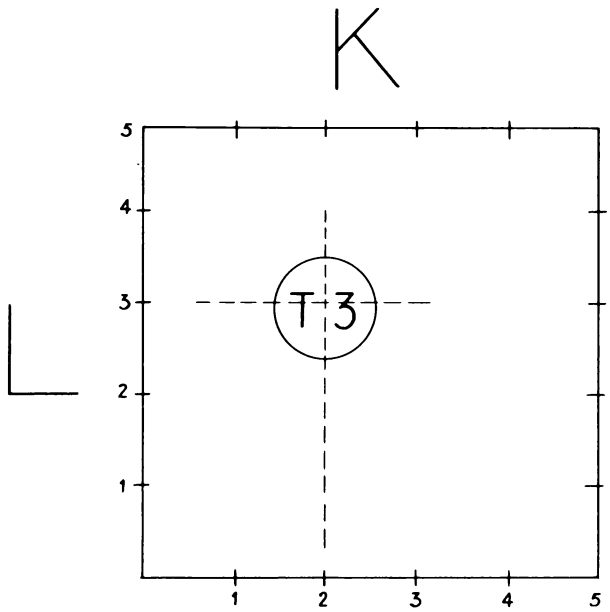

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Figure 6A4.—Locating a Bogey within a square

the contact. Perhaps they can receive the correct IFF response or locate the contact on their ECM gear. If the IFF equipment fails to identify, maybe the contact can be recognized by evaluating ECM radar characteristics. You might also identify the bogey by accounting for all of the known friendlies in the area. This process of elimination and the evaluation of ECM information consume time, and time is not always available. If time is short and we can't receive the correct IFF response, we must assume that the contact is an enemy.

Most of the defensive decisions for the group will be made by the AAW commander, but each ship is set up to evaluate independently, and to make its own decisions if necessary. The factors and questions which follow are considered simultaneously by the AAW commander and each ship's CIC evaluator.

The evaluator is responsible for identifying the contact, and for determining the type of attack he is most likely to make. He is also responsible for an estimation of the target's weapon release range. Generally speaking, the determination of the target's weapon release range is not of paramount importance when intercepting with aircraft, since the practice is to get out there with CAP as soon as possible. It would be a definite factor however, in the case of a saturated raid when the evaluator must select the most critical target. The most critical target, excluding the type of weapon he carries, is usually the target with the nearest or quickest CPA (closest point of approach), or a target involved in jamming.

The target's radar characteristics, along with his speed and altitude, may reveal his aircraft type and, therefore, his weapon capability. Armed with this information, the evaluator, who is well versed in aircraft tactics, can make an educated guess as to which is the most critical target in regard to weapon type and release point.

Along with the selection of the most critical target comes the necessity to know the ship's defensive capability. The evaluator must be knowledgeable in this area in order to recommend the type of armament to be used in the kill, and to be reasonably sure that the selected weapon is capable of a kill. What are the weapon limitations? How high and how far can the missiles go? Is the missile control equipment locked on and ready? Will the target enter the missile blind zone (firing cutout area caused by ship's structure)? If so, will the ship have sufficient time to change course and unmask her missile battery? Or, would it be better to fire a nuclear missile in the face of a concentrated raid? Are these nuclear missiles available? For that matter, what is the actual count of all missiles remaining on board?

Further, are all of the missile directors engaged? Can AA gunfire cope with a particular target? Once again, how high is he, what is his relative movement, is he in the blind zone, or will he reach his weapon release point beyond the range of AA gunfire? In the latter case, perhaps a shifting of targets at one of the missile directors is indicated. These are only some of the many questions confronting the CIC evaluator.

All intelligence information is collected and made available to the evaluator. A knowledge of enemy aircraft capabilities and limitations, both in equipment and tactical application, is essential. The evaluator must be able to estimate the target's priorities and probable intentions. He must be aware of the geographical location of friendly forces, particularly in relation to enemy air facilities. In addition, he must keep abreast of any weather or atmospheric developments and their effect on flight operations and radar performance.

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Evaluation is a process which involves a continuing appraisal, or estimate of the existing air threat. It terminates with the "splashing of the target." With very little time available to detect and successfully counter a raid, it is mandatory that responsibilities be decentralized as much as possible. There may be no time for the commanding officer to request permission of the AAWC (AntiAir Warfare Commander) to launch short range missiles, and there may be no time for the evaluator to ask the commanding officer for permission to take the raid with CAP. And sometimes, when confronted with a surprise attack, there is no time for the weapons officer to wait for information from CIC. As a matter of fact, the director officer may commence firing if the situation warrants.

4. Disseminating. Transmitting information to the other units in the group, and keeping stations on a ship informed, is disseminating externally and internally, respectively. External dissemination to other AAW units, and the AAW commander, is the responsibility of CIC personnel. Internal dissemination is of more concern to the readers of this text.

All ships use sound-powered telephones to complete the communications link between CIC and weapons' battle stations. Newer ships, specifically those armed with missiles, often have closed-circuit television equipment on board. A television camera is focused on the phase 2 plot in CIC and receivers are located in various control stations throughout the ship. Examples of receiving stations are:

a. Weapons Control Station
b. Commanding Officer's Tactical Plot
c. Flag Plot
d. Air Control Section of CIC

Television equipment has done much to eliminate the excessive time consumed when transferring bogey data exclusively by sound-powered telephones. But telephones are still used for action commands and to provide an audio backup for visual information. They continue to be the sole information link to stations that do not have a critical evaluation or a weapons control assignment.

The most important information disseminator for weapons personnel is the weapons liaison officer (WLO). This officer is stationed in CIC at a location which commands a good view of the phase plots and facilitates direct conversation with the evaluator. The WLO is on the weapons battle control telephone circuit, which also includes all officers who are assigned in weapon control stations. It is his responsibility to keep all stations on the circuit fully informed in all matters pertaining to the battle. He forwards information such as "warning red, yellow, or white" which means that an attack is imminent, probable, or improbable. Warning conditions are prescribed further by "weapons tight" or "weapons free." Weapons tight means that shipboard weapons will not be fired (unless enemy aircraft are committing hostile acts) because friendly forces (usually CAP) are in the firing area. Weapons free means that there are no weapon delivery restrictions, and may be used as the authorization for a ship to "fire when ready." The latter usage depends on the standard operating procedure for the task group. The WLO performs other, more mechanical, actions in getting directors on targets; these will be discussed in sections C and D of this chapter.

5. Destroying. There is very little we can say here about destroying targets. Once a gun projectile is launched it follows a ballistic flight plan which cannot be controlled by the launching ship. Effective gunfire depends on solving the fire control problem, aiming the guns correctly, and maintaining a continuous ammunition supply. The destruction of targets by missiles will be discussed in the next two volumes of this series.

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B. Target Detection

6B1. DETECTING EQUIPMENT

It is possible to detect a target by using passive equipment such as electronic countermeasure (ECM) gear. This supersensitive equipment detects electromagnetic radiation, indicates its direction, and measures the transmitter's frequency, pulse width, and pulse repetition rate (PRR). We can even determine the antenna's rotation rate with this gear.

The ECM operator refers to a publication which describes the operating characteristics of known radiating equipment. He then ascertains what type of equipment he has detected and, more important, what type of vehicle the equipment is probably mounted on. In other words, he makes an educated guess as to whether the contact is a particular type of enemy aircraft, submarine, or perhaps a member of his own operating force. ECM gear has serious drawbacks in that it cannot measure the range or altitude of the contact, even though range might possibly be determined by ECM triangulation.

Air search radar is the primary means by which we detect targets. The air search radar fixes the target's position in two coordinates—range and bearing. Some CIC air search radars, particularly those associated directly with fire control equipment, have a height or altitude finding capability. The three coordinate radars have a distinct advantage when designating a fire control director to the target. The height quantity is converted into an angle of elevation and eliminates large sector searching in elevation by the director. In order to make use of height, we must have a weapon direction system which can designate in three coordinates. The result is a decrease in the target acquisition time required by the fire control director, provided the search radar has been correctly aligned with the FC radar. Since radar is such an integral part of modern weaponry let's discuss it in more detail.

6B2. ELEMENTARY RADAR THEORY

As you remember from an earlier chapter radar essentially is a method for determining, by radio echoes, the presence of objects, their range, bearing, and elevation, for recognizing certain of their characteristics, and for making use of this information. A complete radar installation is itself referred to as a radar; the term is used to denote the equipment as well as the technique.

Here are the bare elements of radar operation (fig. 6B1). A high-powered transmitter sends out a short pulse of intense high-frequency radiation from a special antenna so that it issues more or less as a beam. Then the antenna is switched by a duplexer to a sensitive receiver, which picks up radio echoes reflected by targets in the path of the beam. The echo (pip or blip) shows up as a bright spot or a kinked line on the screen of a cathode-ray tube. (The tube is like that of a television receiver, but doesn't present a picture—only blips or pips.) The functioning of the system is coordinated by a timer, which transmits pulses to the receiver and keyer. The keyer in turn starts and stops the transmitter.

With electromagnetic radiation traveling at the speed of light (186,000 miles per second), its obvious that all this happens pretty fast. Let us first look in further detail at one key component of the system—the cathode-ray tube—and then observe the functioning of the system in slow motion.

6B3. THE CATHODE-RAY TUBE

The cathode-ray tube is one of the most versatile electronic devices ever invented. In this application, it functions as a kind of electronic stopwatch. It can function in many other ways. A close but brief look at its anatomy now will clarify its functioning.

As shown in figure 6B2, a narrow high-velocity stream of electrons shoots out of the electron gun in the neck of the tube and hits the fluorescent screen on the large end of the tube, which glows at the point where the electrons strike. Between the gun and the screen, the electron beam passes between a pair of vertical deflection plates and a pair of horizontal deflection plates. If a variable voltage is applied to the horizontal plates, the beam can be made to sweep back and forth in a horizontal line. If a voltage is applied to the vertical deflection plates, the beam can be made to deflect in a vertical direction. If a voltage to the vertical deflection plates is used in conjunction with the voltage to the horizontal deflection plates, a horizontal

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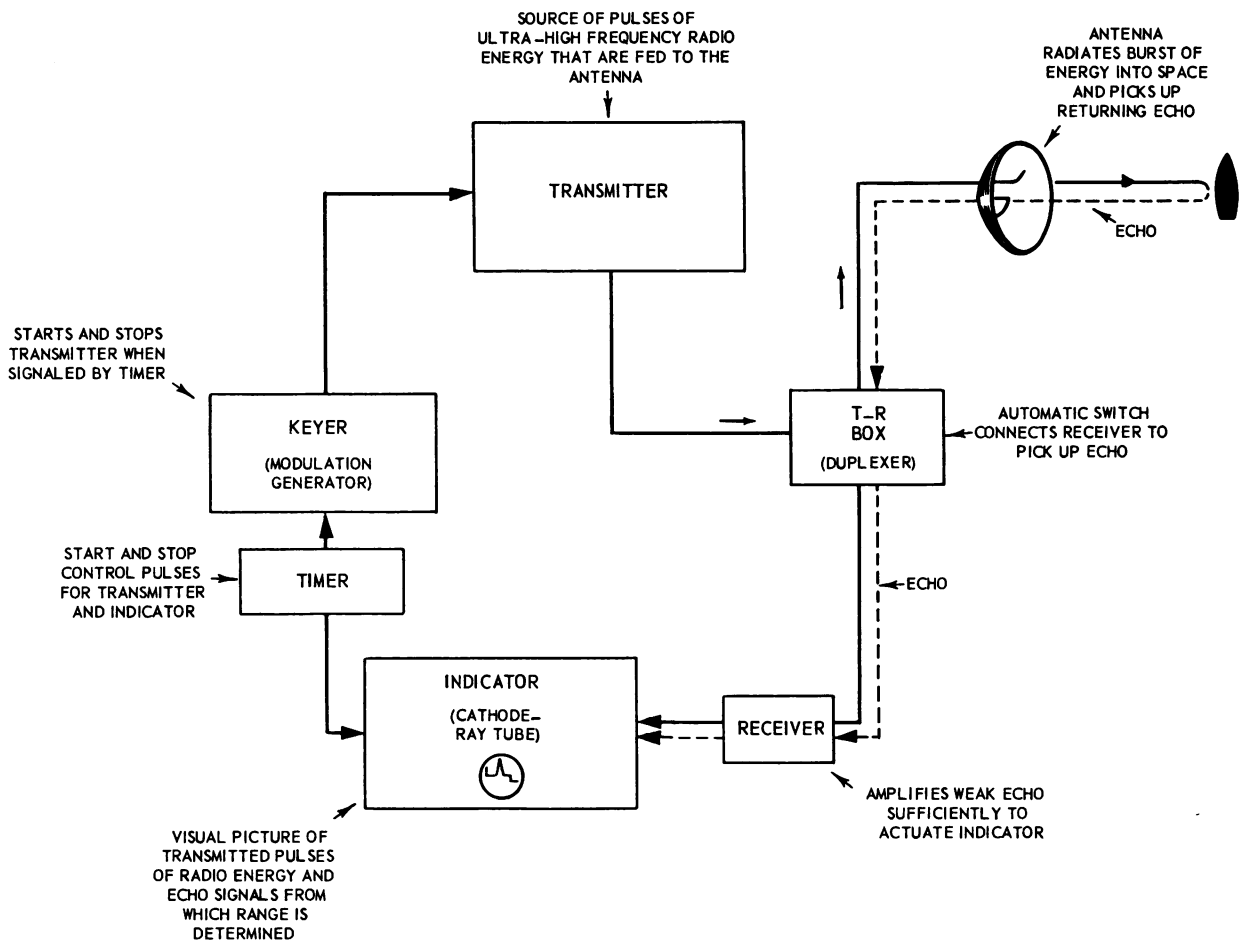

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Figure 6B1.—Elements of a Radar System (block diagram).

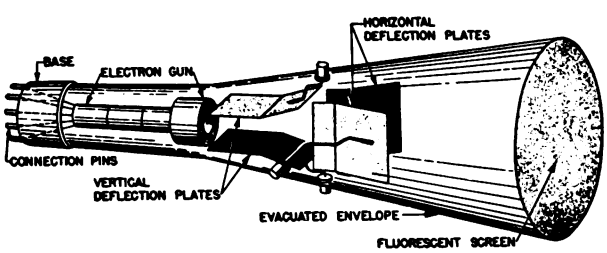

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Figure 6B2.—Anatomy of a Cathode Ray Tube (simplified).

line deflected upward at certain points can be produced.

This description applies directly to one type of radar display—the A-scope—described below. In this, the voltage to the horizontal deflection causes the beam of electrons to sweep across the screen at a constant rate; thus successive beam positions can be used as a measure of time. In other types of presentation, combinations of vertical and horizontal deflecting currents are used to produce the patterns.

For the present we shall deal only with the elementary type A presentation.

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6B4. RANGE MEASUREMENT

Radio energy, like light, travels at a speed of 186,000 miles per second. In $\frac{1}{1,000,000}$ second (1 microsecond) it travels 328 yards. If the beam of electrons in the cathode tube is synchronized with an outgoing pulse of radio energy, by the time the pulse has traveled 3280 yards the beam of electrons has been sweeping across the screen for 10 microseconds. Since the pulse has to travel to the target and return, a time indication of 10 microseconds on the cathode-ray tube represents a range of 1640 yards, although the pulse has actually traveled 3280 yards going to the target and returning. To put it another way, 6.1 microseconds on the scope is equivalent to 1000 yards in range.

Actually the movement of each sweep is so fast and the interval between sweeps so short that the eye does not see the individual sweeps but merely a single line of light. In the A-scope presentation (fig. 6B3), the straight line of the sweep extending across the screen is called the time base. The large deflection at the left end of the time base corresponds to the transmitted pulse. The returning target echo is picked up by the sensitive receiver, and the echo signal voltage impressed on the vertical deflection plates of the cathode-ray tube deflects the beam of electrons momentarily upward. This makes a pip or blip in the time base at a point representing the time at which the echo returns.

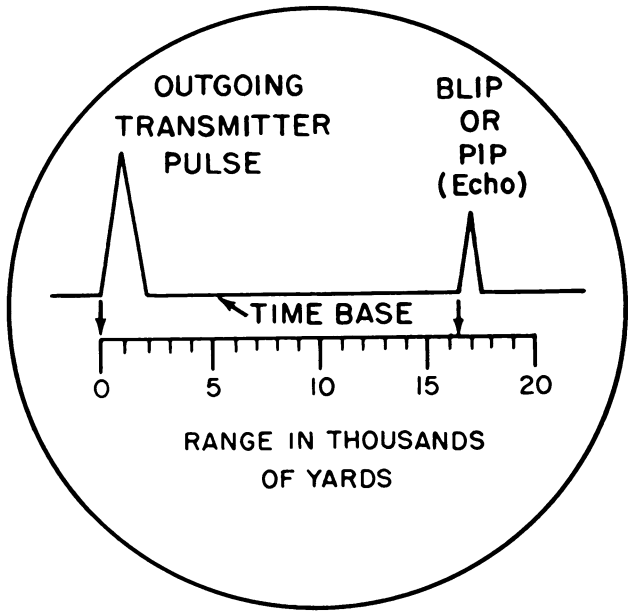

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Figure 6B3.—A Scope Presentation (schematic)

6B5. GENERAL TYPES OF RADAR DISPLAYS

Cathode-ray indicators (called scopes or indicator scopes) may operate on one of two principles, i.e., deflection modulation or intensity modulation.

DEFLECTION MODULATION. Typical of the deflection-modulated type is the A-scope already mentioned. In this type, the electron beam is moved across the scope in a line, and target returns (blips) are indicated as deflections of this line. The transmitted pulse is also indicated as a deflection. The sweep or electron line is called the time base. The linear distance of the target blip from the transmitted pulse is an indication of the time of travel of the pulse to the target and return. Consequently, the time base may be calibrated to represent the range to the target.

INTENSITY MODULATION. In an intensity-modulated scope, the returning target echo causes an increase in the intensity of the electron stream, rather than a deflection of it. Thus, the target blip appears as a bright spot which may be used to represent combinations of target range and direction by its position on the scope. The commonest example of this type of display is the plan position indicator (PPI) shown in figure 6B4. The indicator is fed by the signal from a continuously rotating antenna. The indicator scope shows, in polar coordinates, a radar map of the area being covered, with own ship at the center of the screen. Range is indicated by the radial distance from the center of the screen to the target blip. The beam or time trace moves radially outward and rotates continuously in accordance with antenna rotation through 360 degrees. The top (or 12 o'clock position) of the indicator screen may be set to represent either the direction of ship's bow or true north, so the angular distance of the target echo from the top of the scope is a representation of relative or true target bearing respectively.

The B-scope and T and E (train and elevation) scope (fig. 6B5) are other examples of intensity-modulated scopes. The B-scope provides a rectangular presentation of a small segment of the area, with range indicated vertically

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and bearing horizontally. The T and E scope presents a view of a plane perpendicular to the antenna axis, with bearing indicated horizontally and elevation vertically. The presentation is therefore similar to the view through a gunsight telescope.

A later article will discuss in further detail certain special types of fire control radarscope display not taken up here.

6B6. SEARCH RADAR AND IFF

Aboard ship, radar equipment has two general applications—for search and for fire control. Search radar displays are centered in CIC. Although we are primarily concerned with fire control radar, you must in order to understand the target detection and acquisition process know something about search radar. The three types most commonly used in surface ships are air search, height-finding search, and surface search.

An air search radar's primary function is warning of the presence of aircraft at extreme ranges. It is called a two-coordinate radar since it measures only range and bearing.

Height-finding radars are three-coordinate radars. They are capable of discriminating between targets that are close together, and they are capable of measuring range, bearing, and altitude. The altitude quantity is converted in the weapon direction system to an angle of elevation for use in directing fire control directors to the target. Three-coordinate radars eliminate the need for large sector searching in elevation by the fire control directors, thereby decreasing their target acquisition time.

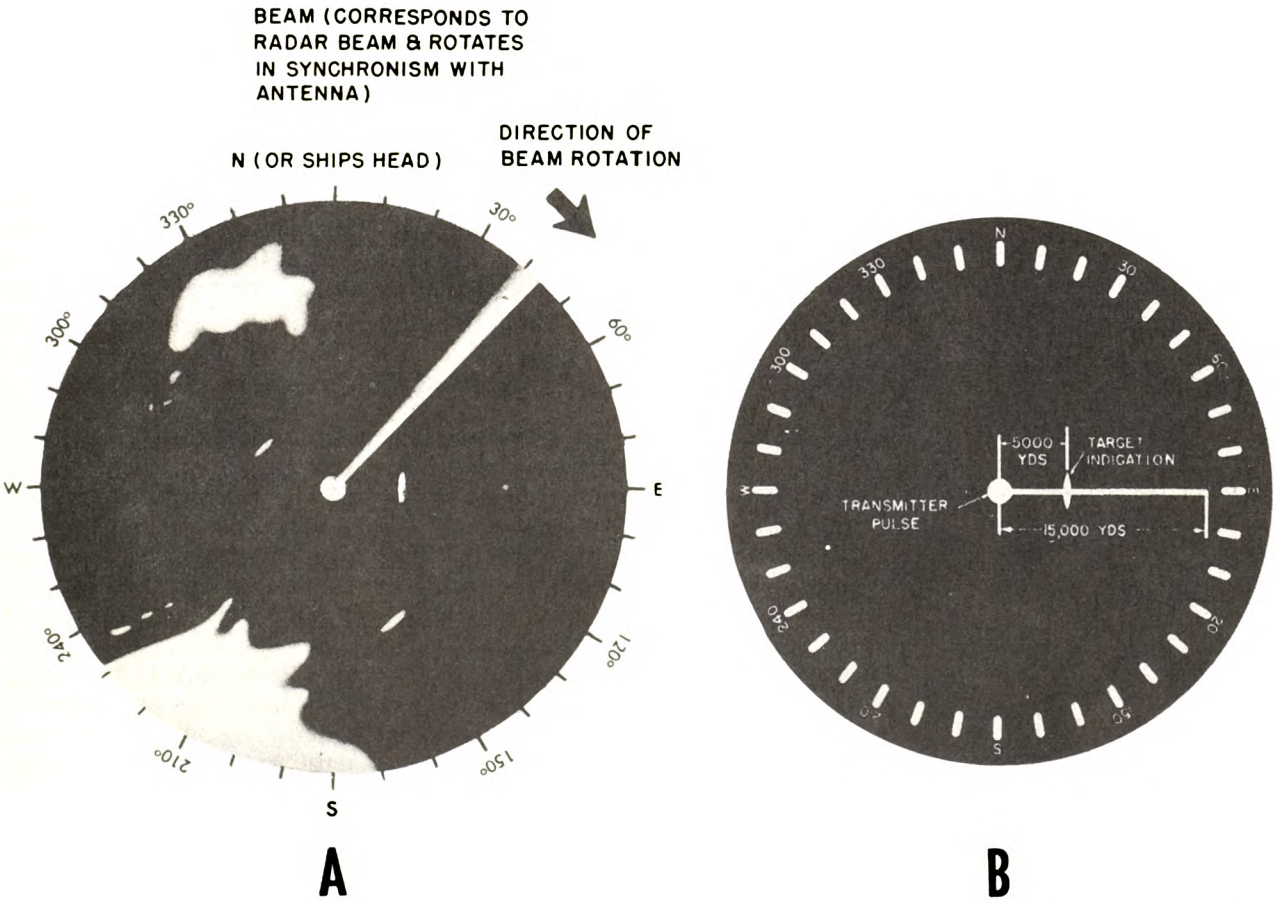

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Figure 6B4.—PPI Scope presentation.

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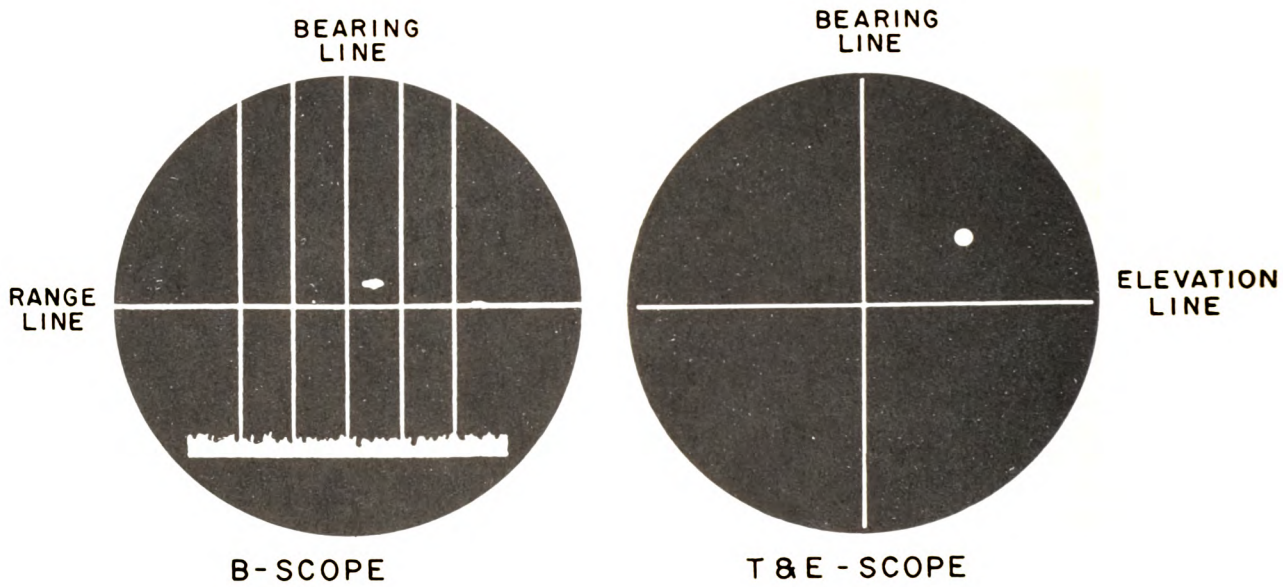

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Figure 6B5.—B-scope and T and E scope.

Surface search radars measure the range and bearing of surface contacts to assist in navigating the ship, or to send surface target information to the weapon direction system. They are also effective in detecting low flying aircraft, since their radar energy is concentrated at low angles of elevation.

As we have mentioned above, on a radarscope presentation a target is a blip, not a picture. It's either a shapeless blurred spot or patch, or a jagged distortion in a line. Around the blip is "grass"—the visual equivalent of audible noise in a radio transmission. (It's called "grass" because in an A-scope presentation electronic noise in the line traced by the electron beam in the cathode-ray tube does appear as wavering, moving filaments reminiscent of blades of grass.) In search radar units, any target smaller than a geographical feature has no discernible shape. This is especially true of aircraft targets. When aircraft come within search radar range, there's nothing in the blips to indicate whether they're friendly or enemy.

To deal with this problem we have IFF. IFF equipment aboard ship functions in conjunction with a search radar, but the IFF system includes also equipment aboard the aircraft. The radar beam from the interrogating ship "triggers" automatically the IFF equipment on the friendly target. The latter then transmits a coded signal which shows up on the indicator scope of the regular radar set on the interrogating ship. The interrogating ship and the target must carry matching IFF equipment. For security, we use coded signals.

6B7. FIRE CONTROL RADAR

Fire control radars must be able to determine range, bearing, and elevation of a target with a high precision to achieve destructive gunfire. They must also have good target resolution; i.e., they must be able to distinguish between blips which are very close together. This is necessary to permit accurate pointing, training, and spotting.

Surface Fire Control Radar Mk 13 is used in conjunction with surface batteries on cruisers. This radar must measure range and bearing accurately to provide data for the solution of the surface fire control problem. Figure 6B5 shows a B-scope of the type used in surface fire control radar. The transmitted pulse and the start of the time-base sweep are on the bottom horizontal line. The sweep is made to move from bottom (minimum range) to top (maximum range) on the scope face. The range line is an electronic measuring indication which is made to move up

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and down the scope face in response to mechanical gearing and electronic circuitry controlled by the radar operator. To measure range, the operator rotates a handwheel until the range line just touches the bottom edge of the target echo and then reads a range counter; we are slightly under ranged in the figure.

Notice the five vertical lines in the figure; these are not sweep traces. The intensity of the sweep traces has been decreased by the operator so that he can better see the target pip. If the intensity were increased to maximum, the scope face would be illuminated within the limits of the horizontal transmitted pulse line. This tells you that there exists a vertical range sweep for each minute horizontal segment of the transmitted pulse line. The actual number of range sweeps is determined by the pulse repetition frequency of the radar and the antenna scanning frequency which will be covered in a moment. In figure 6B1 we learned that a timer fires the transmitter and starts the range sweep simultaneously. The pulse repetition frequency of a radar is the operating frequency of the timer measured in cycles of operation per second.

Now let's measure bearing. The center vertical line is called the bearing line; it always represents the exact trained position of the director. Or you could say that it is aligned with the vertical crosshairs in the director's optical telescopes. If optical tracking is impossible the director can get on target by training right (in the illustration) until the bearing line exactly bisects the target pip. The target would appear to move to the left on the scope as the trainer moves the director and its antenna on target. If optical tracking were used, the bearing reference would be the vertical crosshair in the director trainer's telescope, but the radar picture would be the same as if radar tracking were used.

The bearing relationship between the target echo and the director's line of sight (or the bearing line) is obtained by causing the radar antenna to scan horizontally. Scanning in surface radars means oscillating the antenna back and forth rapidly through a small angle; the center of which is the bearing line of sight of the director. When the director is exactly on target, the target is illuminated on the scope when the antenna is at the middle of its scanning arc, thus causing the bearing line to bisect the target echo. In figure 6B5 the target was illuminated when the radar beam was positioned to the right of the line of sight. To present this relationship electronically the vertical range sweeps (without which no pip indication is possible) are made to scan left and right on the scope. When the antenna is at its farthest rightward position, the range sweep will be farthest to the right on the scope. When the antenna scans back to the middle of its arc, the range sweep occurs coincident with the bearing line, and so on. The sweep is made to scan left and right by applying an a-c signal to the scope's horizontal deflection plates: the same a-c signal which drives the antenna back and forth. The other vertical lines in the figure are spotting reference lines for deflection spots.

Antiaircraft fire control radar is more complicated than surface fire control radar. This is due primarily to (1) greater target velocities, (2) target elevation measurement, and (3) a need for automatic radar tracking. The automatic tracking feature is not found in all AA systems, but it is included in all missile systems and in the newer gunfire systems. In this discussion we'll concentrate on the automatic tracking Mk 35—the radar used with the Mk 56 GFCS.

The Mk 56 system has four displays—a double display for range (the A/R-scope), a display for bearing (the B-scope), and a display for elevation (the E-scope).

The A/R-scope displays two traces—the A trace and the R trace. The A trace extends from zero to 30,000 yards. The significant features of the trace as illustrated in figure 6B6 are:

1. Outgoing transmitter pulse blip. This is an up-down jog of the trace at the zero range point.

2. Range notch. This is a depressed portion of the trace. By cranking a control on the radar console the operator can shift the notch in range so that target blips may fall within it, as illustrated in the figure. When the notch is adjusted so that a target blip is in contact with the left-hand side, the target is said to be gated.

3. Target blips. These are up-down jogs of the trace, each corresponding to one target.

The R trace is an expansion of a portion of the A trace. Only the left side of the range notch shows on the R trace; this is the range step. The R trace is 1000 yards long; there is a small gap in the trace to represent the location of the nearest even 1000-yard point in range. As the radar operator cranks the range notch uprange or downrange, it moves correspondingly on the A trace, but on the R trace the range step remains fixed in the center of the trace while the blips and range markers move past it. In addition,

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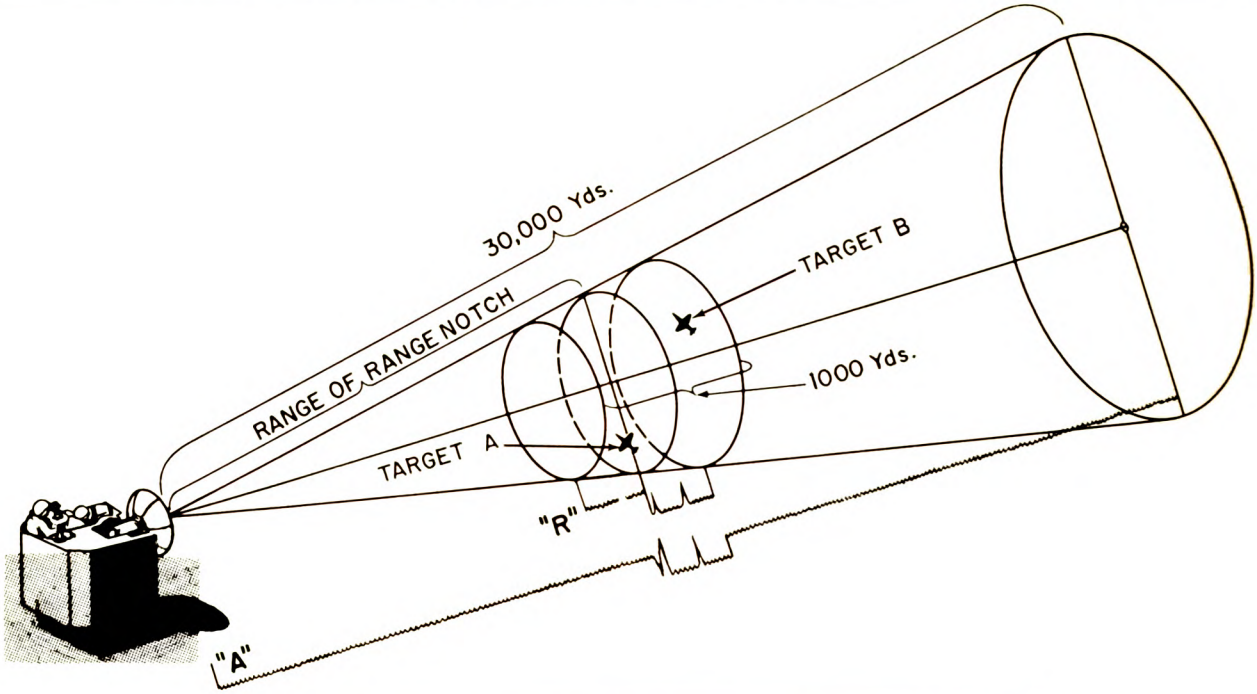

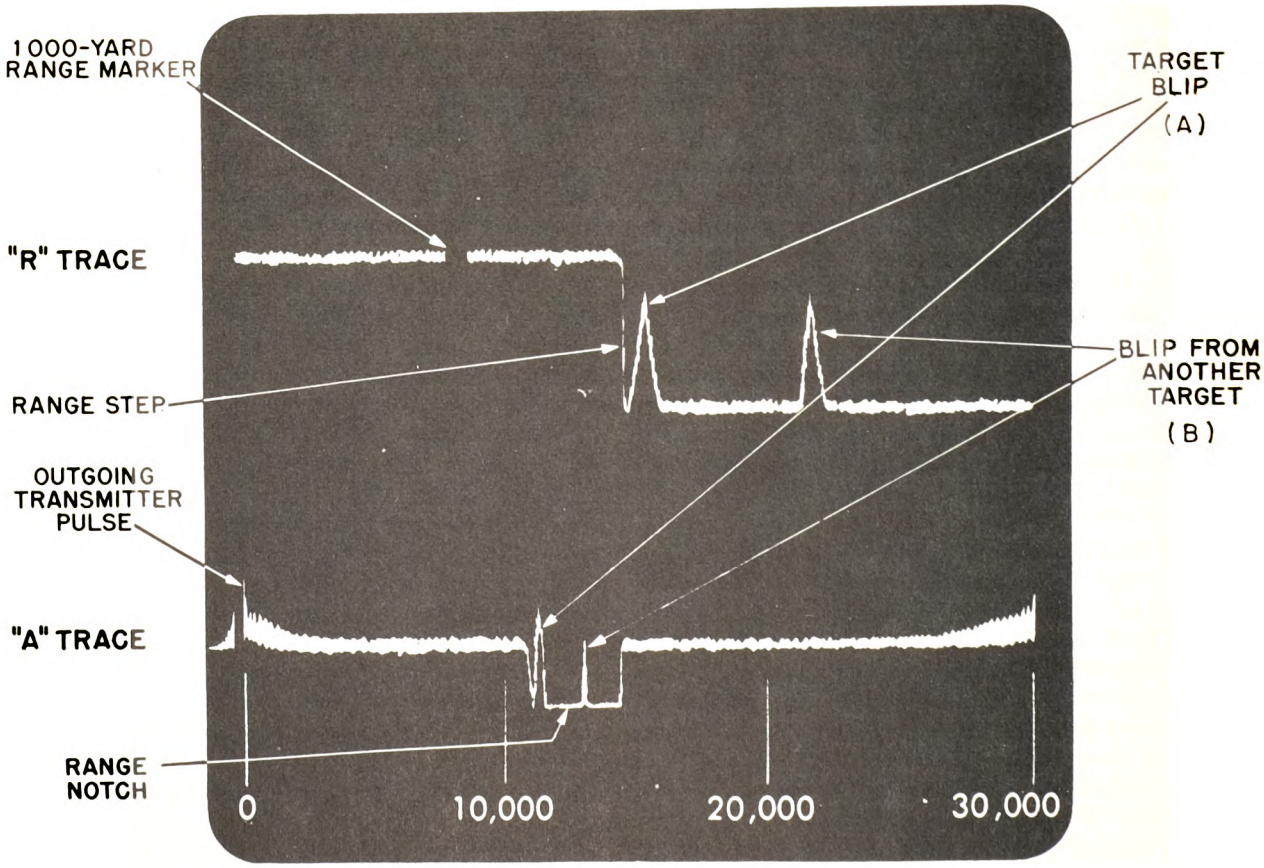

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Figure 6B6.—A/R-scope presentation.

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the blips move leftward or rightward on both traces to correspond to their movements downrange (decreasing range) or uprange.

The diagram above the illustrated A/R traces in figure 6B6 shows the spatial relationship of radar and targets which the traces indicate.

The E-scope (fig. 6B7) shows range (horizontally) from 0 to 30,000 yards, and director true elevation (vertically) in degrees from -10 degrees to +90 degrees. The vertical width of the trace depends on the type of antenna scan. There are two types of scan—spiral for searching and conical after the radar has locked onto target. As the radar beam goes through a complete spiral scan cycle, the trace covers a 12-degree band, the center of which is at the angle corresponding to the true elevation of the director. In conical scan, the trace covers a 3-degree band. The range strobe line (range mark) appears as a bright vertical line extending from top to bottom of the sweep. Target echoes appear as short vertical lines. Two curved lines on the scope face furnish an indication of target altitude in feet. A target on the lower curved line is at 10,000 feet altitude; target on the upper line is at 30,000 feet altitude. Other target altitudes can be estimated.

The B-scope presentation (fig. 6B8) shows bearing (horizontally) 6 degrees either side of director train, and range (vertically) 1000 yards either side of the range mark. The trace appears as a vertical band, with its center always at the center of the scope. The trace width in bearing depends on antenna scan: 3 degrees for conical scan, and 12 degrees for spiral scan. The range mark appears as a horizontal line at the center of the scope, extending across the entire width of the trace. Target blips appear as horizontal lines.

When searching for a target, the radar tracker watches the E-scope. Since spiral scan is used for searching, the target blip will be visible on the E-scope when the director line of sight is within 6 degrees of target bearing and 6 degrees of target elevation. In addition, for the blip to be visible on the B-scope, the range mark must be within 1000 yards of the target blip. As soon as the target blip appears on the E-scope, the radar operator slews the range mark to bring the blip within the B-scope. When the radar tracker sees the target in the B-scope, he turns the range crank to bring the blip up or down to the range line, and simultaneously turns the bearing crank to bring the blip right or left to the director bearing line.

Figure 6B9 shows the appearance of all three radar scopes for different positions of the target. The equipment is on target C; therefore the blip from target C is against the range notch on the A sweep, at the step on the R sweep, at the center of the trace in the E-scope, and at the center of the B-scope. All targets covered by the 12-degree spiral scan appear on the A sweep and E-scope. Target E does not appear on any scope because it is more than 6 degrees from the antenna axis. Target A does not appear on the B-scope because it is more than 1000 yards from the range mark. Targets A and D do not appear on the R sweep because they are more than 500 yards away from the range step.

When the target selected is gated in the A/R scope, and is (as target C is) on the intersection of the zero lines in the B-scope, the radar operator can by operating a foot switch cause the system to track the target automatically.

6B8. DIFFICULTIES IN DETECTING

Atmospheric conditions will sometimes affect target detection. A moisture-laden cloud might appear to be an air contact on the scope. This false target would soon be discounted by the radar operator since it will have a very low speed. Rain squalls, storms, etc., may temporarily obscure actual air contacts. But if we are hampered by weather, the attackers are also. Extreme adverse weather conditions lend some doubt as to the feasibility of an air attack.

Target detection is made more difficult when the enemy is "jamming" our radar. One form of jamming is more or less semiactive and consists of dropping "rope" or "chaff" from an aircraft. This jamming material is made of aluminum foil strips which are cut to resonate at a particular frequency. The effect is similar to what we would see if numerous transmitters were reradiating our air search energy back to us. This type of jamming is easily recognized on the scope because of the almost linear pattern it presents. Its success lies in the aircraft's ability to saturate our scope with false targets thereby obscuring the real ones.

Some electronic countermeasure equipments can be used for active jamming. We are more concerned with enemy aircraft acting in this capacity than surface units because of the latter's range restrictions at radar frequencies. ECM equipments can find automatically your transmitting frequency and pulse repetition rate, and then transmit "down your throat."

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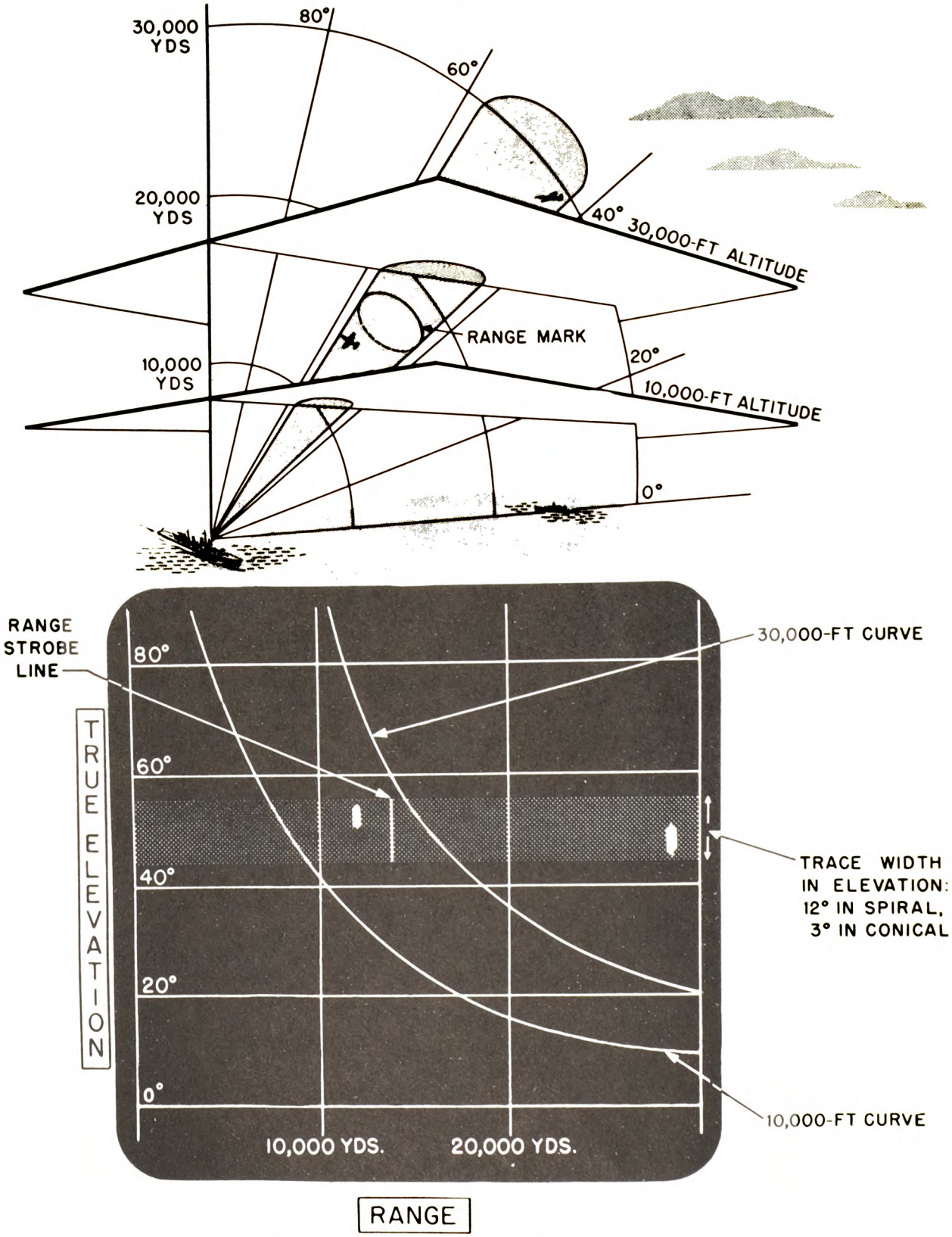

Figure 6B7.—E-scope presentation.

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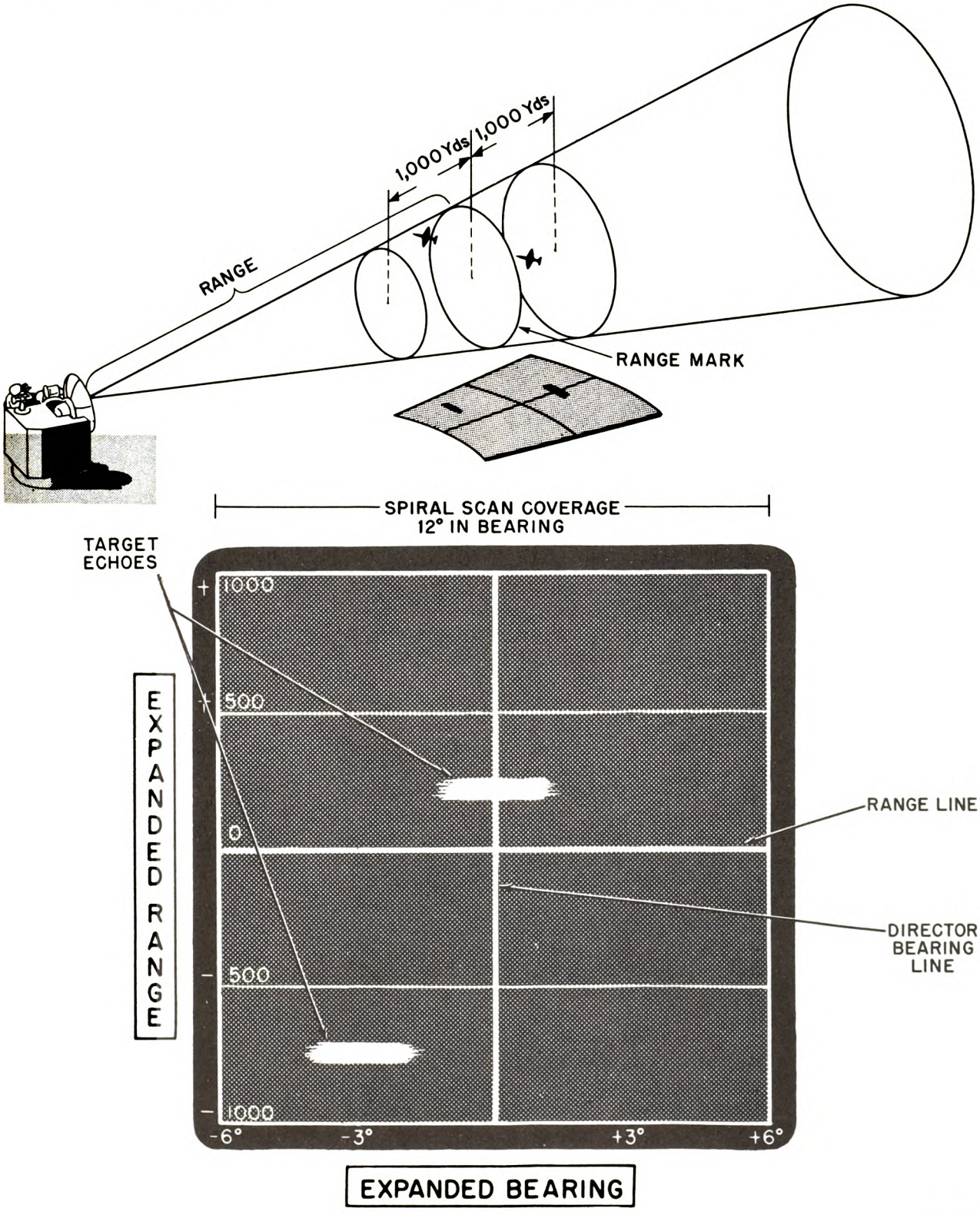

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Figure 6B8.—B-scope presentation.

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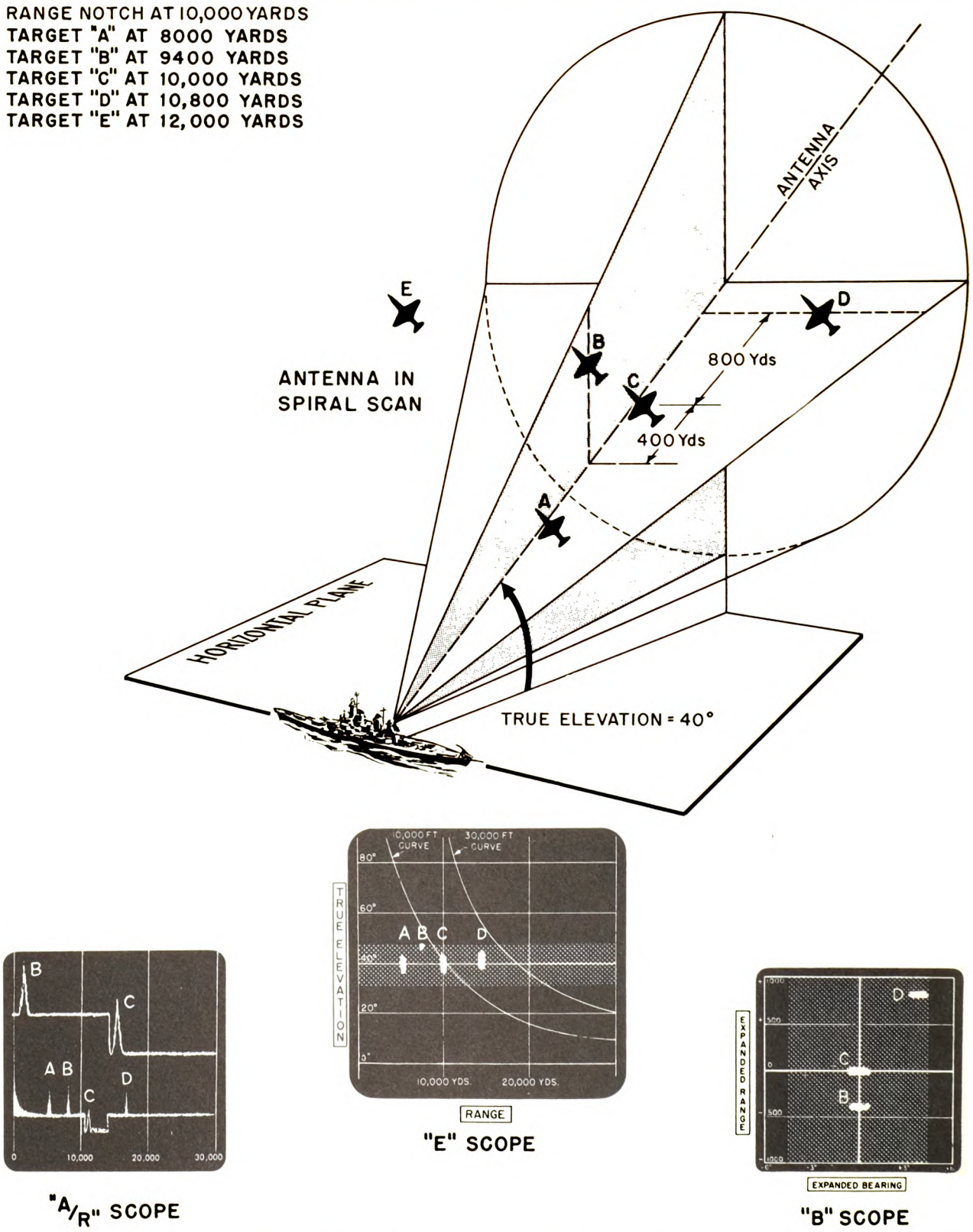

Figure 6B9.—Interpretation of radar traces. 92.35

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On A type radarscopes this type of interference shows up as "railings" or "fence posts." On B type scopes it may look like sine waves or "snow."

What can we do about jamming? To be effective, the chaff aircraft must penetrate our entire AAW network. It is doubtful that he can do this since the chaff pinpoints his position to practically every fire control director in the task group. Also, he would be recognized immediately as an enemy, thus eliminating the normal evaluation time. If he chose to drop chaff outside of our defenses, he would be announcing an attack. Moreover, fire control radars have been known to look right through this chaff.

Many antijam circuits have been incorporated in our modern radars to combat active jamming. Frequency control power devices change transmitting frequencies at the touch of a switch on some radars. Electronic differentiating circuits change the "fence posts" into narrow spikes before they are displayed on the scope. Manually operated pulse repetition controls vary the repetition rate of our radars. Some radars have an automatic pulse repetition variance that operates at a random rate, making it virtually impossible for countermeasure gear to lock on. The fence posts would then wander across the scope but the target's movement would be consistent in direction and therefore easily discernible from the wandering fence posts.

The most pronounced single limiting factor in air searching is the radar's inability to follow the curvature of the earth and detect low altitude targets beyond the horizon. Some radiofrequencies (shortwave) will follow the curvature of the earth for great distances provided the waves are propelled by sufficient power. This is accomplished by bouncing the radio wave between the earth's surface and the ionosphere. Since the ionosphere curves around the earth, the reflected radio waves will curve also.

Shortwaves are in the high frequency range of the spectrum; radar waves are considerably higher in frequency. The higher radar frequencies will penetrate the ionosphere with little or no reflection occurring. They penetrate primarily because of their shorter wavelength. We will not get involved in a discussion concerning the "whys" of this penetration. We are more interested in the end result which is a desirable straight line of sight transmission.

You may have decided at this point that a low frequency radar, making use of the ionosphere reflection phenomenon, could provide adequate coverage of the blind area beyond the horizon. Perhaps it could. The technical problems encountered in this attempt however, would be staggering. We would have to know the height at which reflection of the wave occurs, and the primary factor in this determination is the ionospheric density. Density of ionization at different altitudes makes the ionosphere appear to have layers. Actually there is no sharp dividing line between the layers of ionization. Suppose we could predict how much density is required to reflect the wave, could we then predict with accuracy at what height reflection would occur? Even with an educated guess, we would be further victimized by sporadic ionizations which occur at varying density in each layer.

If we were to suspend ourselves in the ionosphere and look down to the earth's surface with magnified vision, we might be able to see an aircraft standing out in bas-relief against the water. Electronically speaking this is not the case. It would be difficult indeed to detect a target, say, 50 feet above such a massive reflecting surface.

If we did not have a line of sight transmission in radar, the time factor would be in error. Errors in time mean errors in range. Errors in elevation and bearing would also be noted. To sum it up, current knowledge and the need for accuracy forces us to use higher frequencies, thereby making the blind area something with which we'll just have to live.

A straight line extending from the air and surface search antennas and tangent to the horizon, represents the maximum detectable range of zero altitude targets. This range is proportionally increased by an increase in the target's altitude. Detection range could also be extended by raising our antennas' heights. Unfortunately we cannot depend on the targets accommodating us by flying at high altitudes, nor can we raise the heights of the transmitting antennas beyond the restrictions imposed by the ship's designers. We must make another tack.

Instead of considering the AAW unit and its "low flyer" detecting limitations, let's look at the unit as an integral part of a whole. The whole in this case is a task group. Tactically speaking, it is our mission to protect the vital area of the task group and not the units comprising it. Protecting the vital area is easier than protecting a single ship when we discuss the problem in terms of target detection.

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The task group is deployed so that some of the units are operating many miles from task group center. These outer perimeter units extend greatly the task group's radar surveillance. They can be used to destroy a target with their ship's armament or to vector CAP. Still other units with the same capability are strategically placed between the outer perimeter and the task group center.

AEW aircraft are stationed above the task group as insurance against the penetration of the surface units' radar network. This aircraft represents a great increase in radar antenna height; consequently, its radar range capability is limited only by altitude and the design characteristics of its radar. The AEW is a flying station, and can also be used to vector CAP.

C. Director Assignment with a TDS

6C1. INTRODUCTION

Perhaps the term "target designation" evolved from the designation, or target numbering process in CIC. Or, perhaps designation is related to assigning ships to formation stations; such assignments are often prefixed by "desig." But in weaponry, designation means assigning or directing a fire control system to a specific target. A target designation system or a weapon direction system do this job. A TDS directs gun fire control systems and will be discussed in this section. A WDS directs gun fire and missile control systems and will be covered in section D of this chapter.

Toward the close of the Korean War, the usual method of designating a target was by sound-powered telephone. Usually the designation originated with CIC, which plotted target range, bearing, and approximate elevation from information provided by search radar. The WLO (then the GLO) stationed in CIC would call the selected director and give it the target coordinates. The director would then slew in manual control to the coordinates specified, search in that vicinity, and begin tracking the target when it was located. Once a director tracks a target (then and now) the designation process is complete. Fire control system mechanisms and personnel then control all matters prior to target destruction.

We did not list target designation as a separate step in the ship's defense process (article 6A5) because it broadly falls within the "disseminating" category. The same is true for "target acquisition," which is the term used to describe the actions of directors in acquiring targets. Because of their interrelation the actions for designation and acquisition will be covered together in the following articles.

6C2. FUNCTION OF A TARGET DESIGNATION SYSTEM

As you remember from chapter 5, the acquisition part of this sequence of operations could, in such systems as the Mk 56 GFCS, require no more than a very few seconds. With the increasing speed of air targets, it became necessary to shorten the time required for the WLO to communicate target coordinates to the director, and for the director to find and track the target.

In most cases this in effect means transferring target data from one radar system (viz., the broad-beamed search radar) to another (viz., the relatively narrow-focus fire control radar on a specific director). Several systems were soon devised for performing this function. These systems also provide for target designation based on target data derived from visual sightings.

The target designation system doesn't eliminate the necessity for the decisions that must be made in target assignments. What it does is to:

1. present a complete picture of the AAW situation on which the decisions can be based.
2. enable target assignment to be made with a minimum of delay, with a maximum of accuracy, and with a positive indication that the director has engaged the designated target.

Thus any target designation system is essentially a special-purpose high-speed communications and display system, specially designed to perform these functions.

Since there is more than one fire control system and there may be more than one target, deciding which director should track which target can be a difficult decision to make. The

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officer making these decisions must be quick and responsive to the battle situation. He must keep foremost in his mind the kill capability of the fire control system so designated. He must divide the tracking load between systems as much as possible, and he must have some idea as to which is the more critical target. When (as in a saturation raid) the number of targets is greater than the number of directors and gun mounts, assignment of targets becomes a matter requiring quick, accurate judgment of relative threat from each target and of the ability of each director and gun mount to deal with the targets. In protracted air attack, as in a major strike, such decisions must be made almost continuously.

In the preceeding paragraph we mentioned "the officer making these decisions" without naming his title. This is because control doctrine varies with the ship's weapons installation, depending on whether the target is detected optically or by radar. On ships equipped with a TDS, radar-detected targets are designated to the fire control systems by the WLO and the CIC evaluator who work as a team. The weapons officer in the AAW station topside may intercede in radar designations if he deems it necessary to do so. Most optical designations will come from the weapons officer, but this does not mean that director officers or even mount captains have their hands tied in weapon control matters. In wartime emergencies (as outlined by ship's doctrine) they may even commence firing on their own initiative.

6C3. GENERAL DESCRIPTION OF THE MK 5 TDS

The Mk 5 TDS far outnumbers any other TDS in use today. It will be the subject equipment for the remainder of this section. In the Mk 5 target designation system, target information put into the system originates both in CIC (where the target designation station is located for radar-originated designations) and at the AAW station topside (where optical designations originate). The AAW station topside may be called Sky One on destroyers, and Sky One or Sky Two on cruisers. Figure 6C1 shows graphically the key points of the system aboard a destroyer (DD 931 class).

The system is controlled from the AAW station and the target designation station in CIC. Figure 6C2 illustrates the flow of signals through the system. Optical designations may be used to transmit target data from target designation transmitters (TDT) and control units, through a target designation switchboard, to the gun directors. Or radar designations may be used to transmit target data from a search radar display on the designation indicator, through a coordinate converter, and through the target designation switchboard, to the gun directors.

Operators at the designation indicator (PPI) display in the target designation station, or operators at the TDT and control unit in the antiaircraft station, track the target and select directors to receive designation.

Each operator at the designation indicator views the search radar and tactical data on the plan position indicator (PPI) display and controls a joystick which transmits signals to the video generator and the coordinate converter.

At the converter signals are changed from rectangular coordinates to polar coordinates, and then transmitted through the target designation switchboard to the gun directors.

Repeat-back data follow a reverse path from gun directors, through the target designation switchboard, coordinate converter, and video generator, to the designation indicator.

SPECIAL FEATURES OF THE SYSTEM.—The system is a flexible one. Each designation operator may transmit the same target information to one or more gun fire control systems. This allows a maximum concentration of ship fire power. Interdirector transfer is also possible. This can be used to provide increased fire power on a target already being tracked, or to transfer a target from a director approaching its training limit to a director better able to track on the target.

The system furnishes director repeat-back information on a PPI-scope and on indicators that inform designators how long their assistance is required after designations have been made. Luminous semicircles (repeat-back hooks) representing director tracking coordinates are projected on the PPI display. The position of the repeat-back hooks indicates bearing and range from the director.

To avoid duplication of designations, optical designations have priority over radar designations; and optical designations from the starboard side have priority over optical designations from the port side. This permits only one designation to any specific director at any one time.

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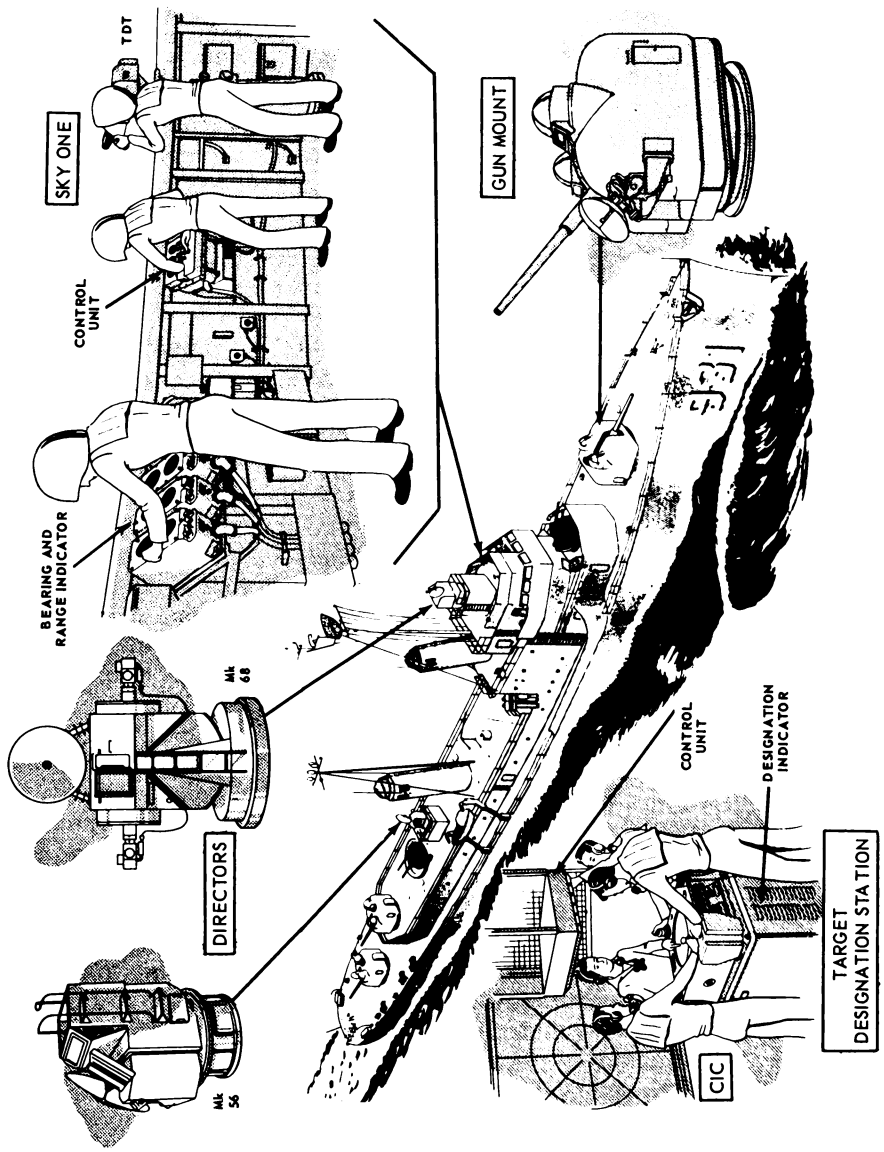

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Figure 6C1.—Target Designation System Mk 5 Mod 7, DD931 class Destroyer.

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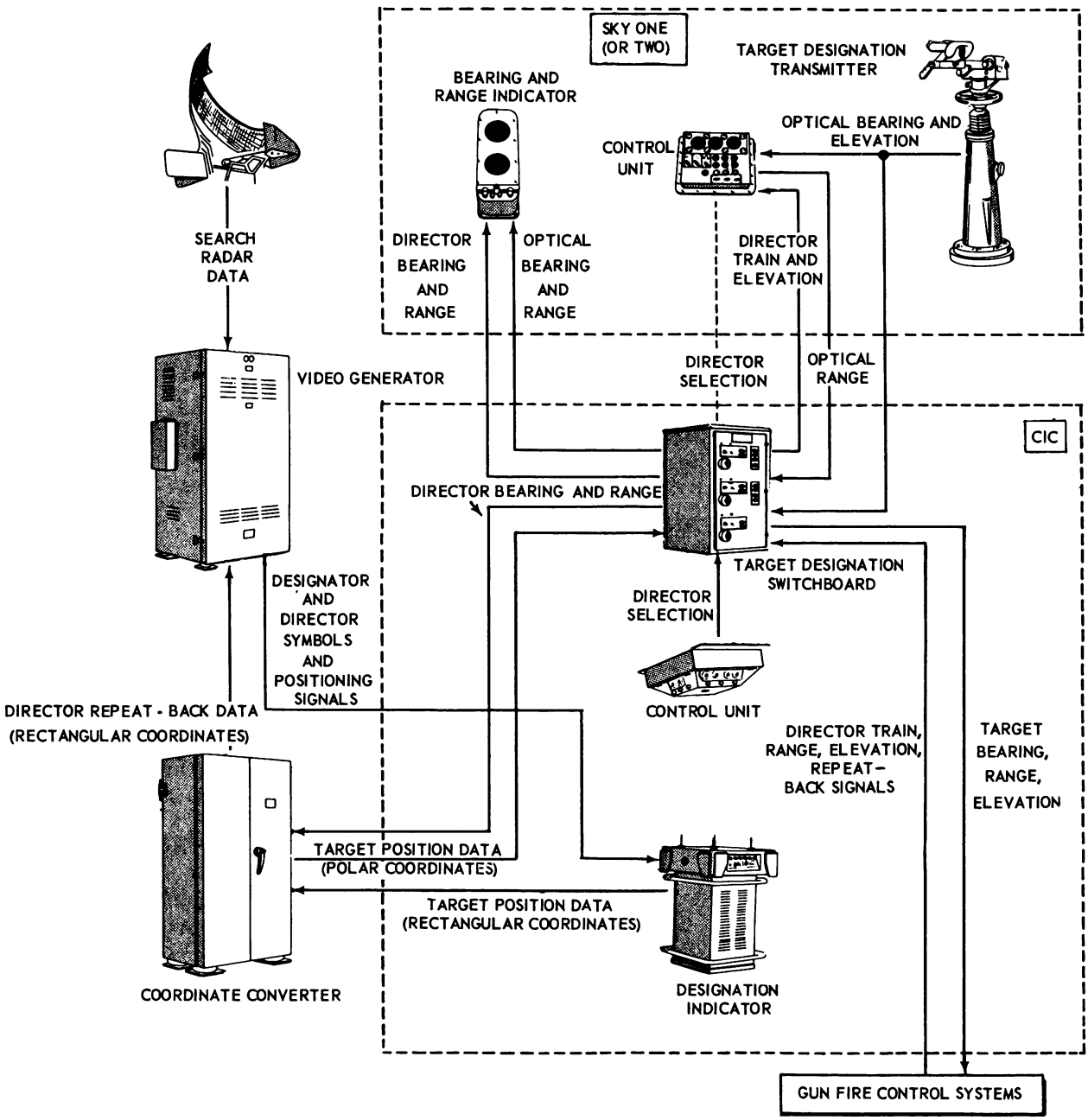

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Figure 6C2.—Mk 5 TDS Data Flow (schematic).

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6C4. DESCRIPTION OF MK 5 TDS EQUIPMENT IN CIC

DESIGNATION INDICATOR.—The display and control center of the Mk 5 TDS is the designation indicator and its overhead control unit, located at the target designation station in CIC. (Figure 6C3.) The station is manned by four men—a supervisor and three designators. The top surface of the indicator console is occupied by a PPI display and four joysticks (one in each corner). The supervisor stands on the side occupied by a control panel. The PPI display (shown schematically in figure 6C4) includes:

1. Bearing dial (calibrated in degrees) and three concentric range markers, permanently marked above and around the PPI tube face.

2. The PPI image originating with the search radar, and including the evolving radar beam, target blips, and other features of the original radar display.

3. Four designate hooks. Each consists of semicircle with a dot at its center. The position of each hook on the display can be controlled by manipulating one of the joysticks.

4. Four repeat-back hooks. These are like the designate hooks, but lack the center dot. The positions of the repeat-back hooks on the display are controlled by selected gun fire control directors.

5. The ship heading marker, which indicates the true bearing of the ship's centerline. As the ship turns, the line revolves around the display.

6. Data manually plotted by the supervisor with grease pencil for use by the designators. The markings are made on a reflection plotter assembly mounted over the face of the PPI-scope. This assembly is a nonparallax, concave, partially mirrored surface, so designed that any marks placed on its surface are reflected to the face of the PPI display. The marks reflected downward appear at the same point regardless of the viewing angle.

OVERHEAD CONTROL UNIT.—This unit is located directly above the designation indicator. (Figure 6C3.) It consists of three designator panels and one supervisor panel. It enables director selections and interdirector designations to be controlled from this location.

The panels are equipped with director status lamps to indicate the method of designation being used; director selector switches, and estimated elevation switches to designate the approximate elevation of the target. (Target elevation is not transmitted automatically.)

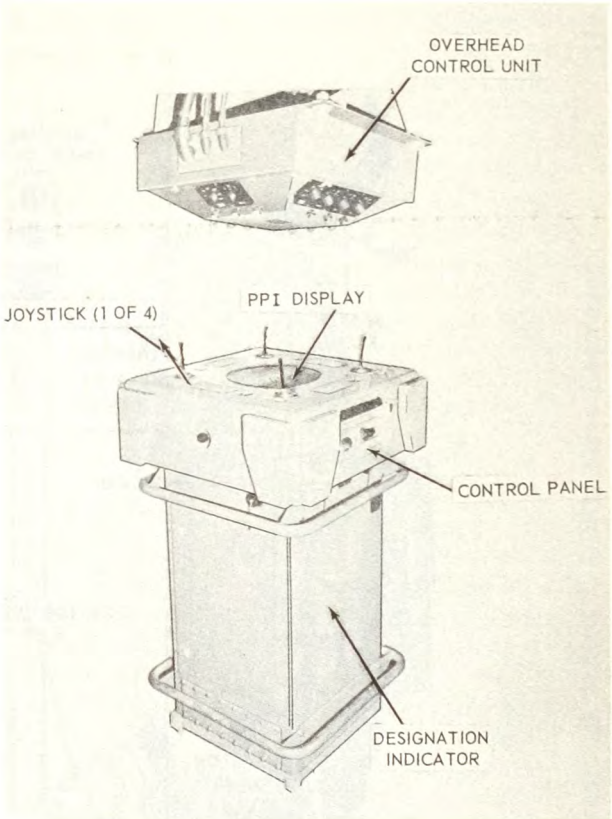

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Figure 6C3.—Mk 5 TDS Target Designation Station.

6C5. DESCRIPTION OF MK 5 TDS EQUIPMENT AT THE AAW STATION

All the TDS equipment at the AAW station is used for designation of optical targets or for indicating the status of the directors. See figure 6C5.

TARGET DESIGNATION TRANSMITTER.—The target designation transmitter or TDT transmits target bearing and elevation data by synchro. The TDT is essentially a weather-protected pedestal on which a pair of binoculars can be quickly mounted or dismounted. As the operator manually trains and elevates the TDT

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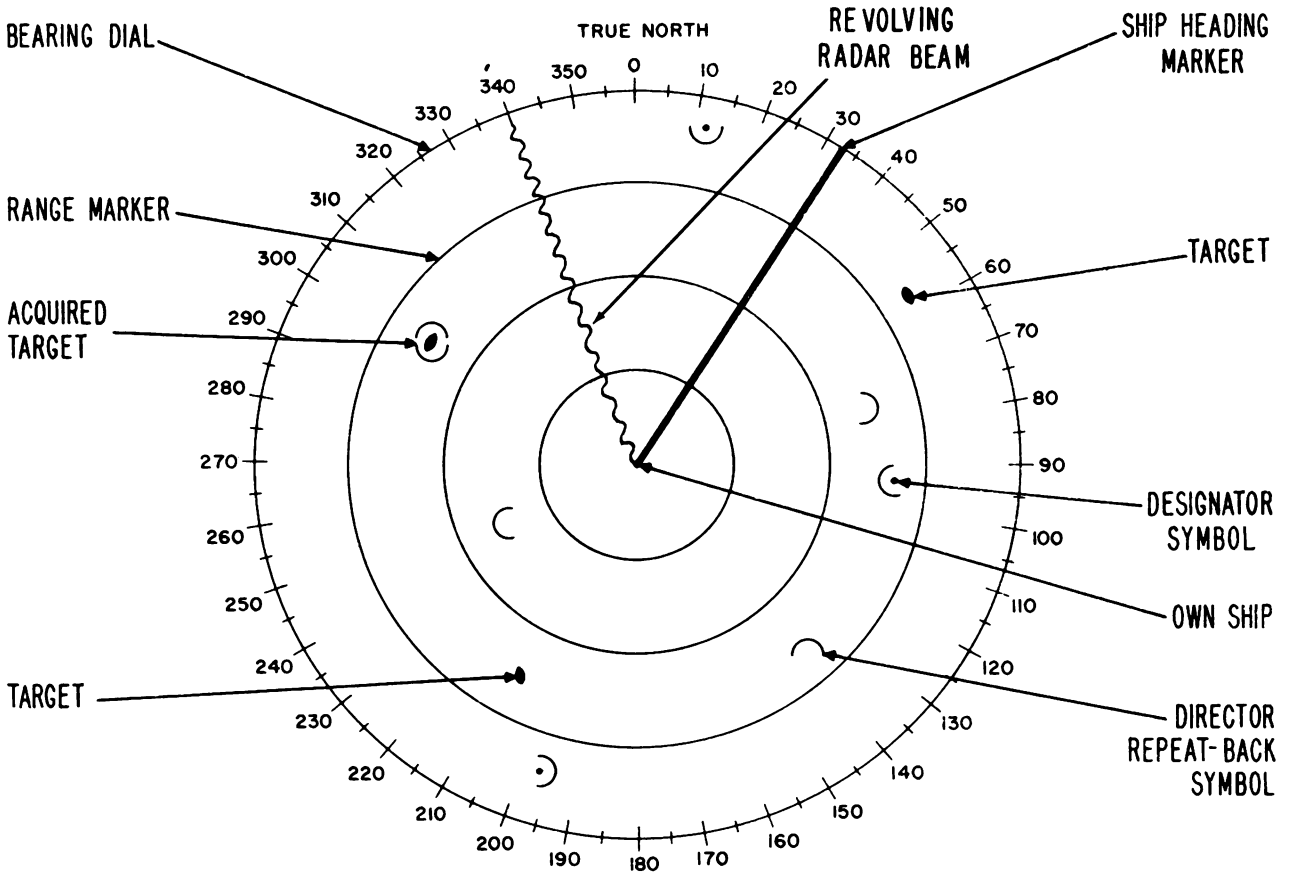

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Figure 6C4.—Mk 5 TDS Designation Indicator PPI presentation (schematic.)

to put the binocular line of sight on target and to track the target, synchro transmitters inside the TDT pedestal continuously register the position of the line of sight. A pushbutton on one of the TDT's handgrips can be used to signal the target designation station in CIC when the TDT has its line of sight on target. The TDT does not provide for direct transmission of range data; range estimates are normally transmitted from the AAW station's control unit. Two TDT's are installed at the AAW station.

BEARING AND RANGE INDICATOR.—This is a multiple device, consisting of a group of several similar units—one for each director. (Not all directors on the ship may be represented by an indicator unit, however.) Each unit has dials which display own-ship course, director bearing and range, and the designated values of target position, and an indicator lamp to show whether the director is tracking the target. The indicator group is situated in front of the AAW officer's station so that he can monitor the status of the directors.

CONTROL UNIT.—This is a three-dial unit; one is associated with each TDT. It displays bearing and elevation information for the TDT and a selected director (one of three may be selected). Signal lights indicate director status. A selector switch can be set to indicate estimated range; this indication is transmitted to the director to which the control unit is switched.

DIRECTOR REPEAT-BACK SELECTOR SWITCH. This switch selects the director to which the control unit is to be connected.

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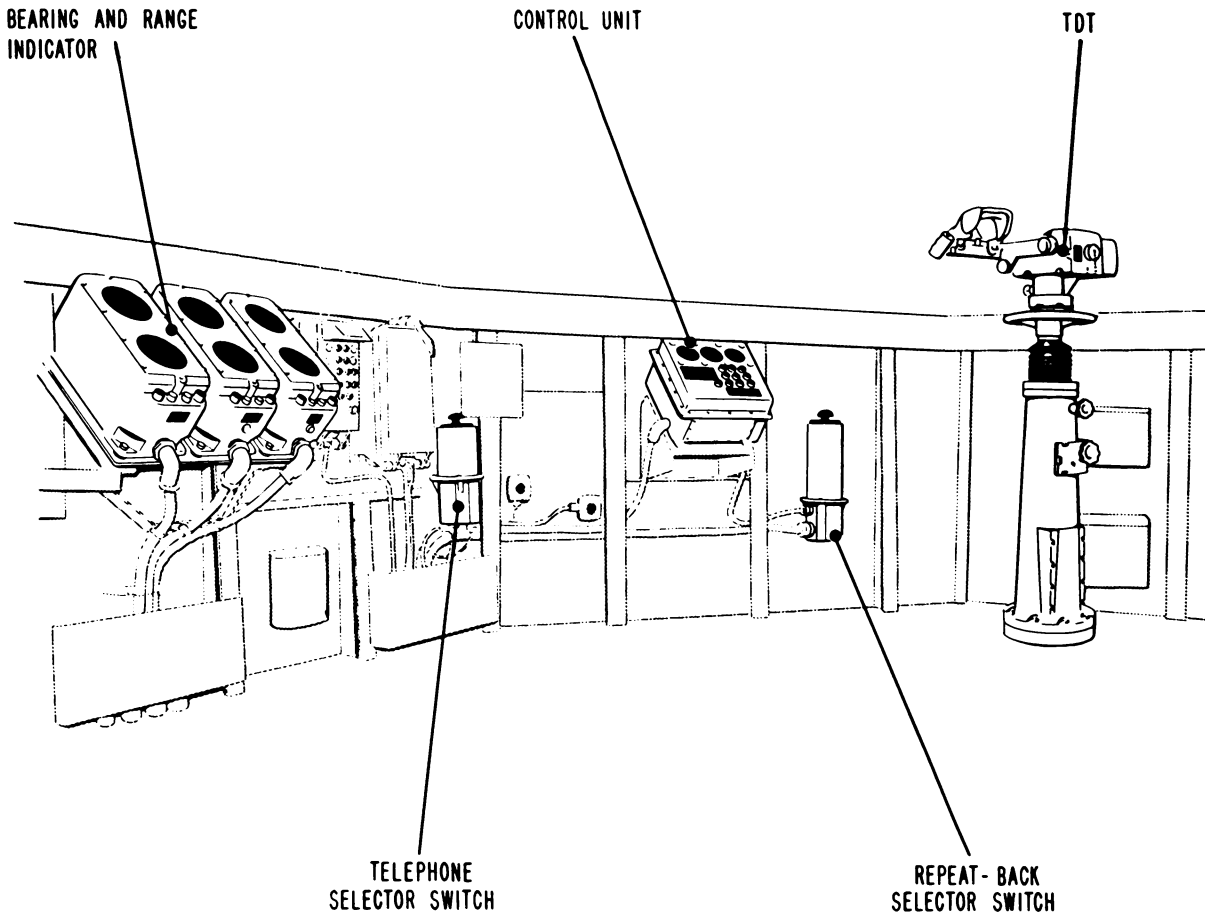

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Figure 6C5.—Mk 5 TDS AAW station.

6C6. OTHER UNITS ASSOCIATED WITH THE MK 5 TDS

Other units associated with the Mk 5 TDS include bearing, range, and elevation indicators located in the fire control system directors, indicator panels, a video generator unit, a coordinate converter unit, and a target designation switchboard.

BEARING, RANGE, AND ELEVATION INDICATORS (not illustrated) are located in the gun fire control directors to display designated range, bearing, elevation, and own ship course. Signal lamps indicate whether the designation is originating with a radar or an optical source.

INDICATOR PANELS (not illustrated) are located in fire control directors to indicate by flashing lamps the source of target designation, and to provide an audible signal to alert director personnel.

The VIDEO GENERATOR AND COORDINATE CONVERTER (fig. 6C2) are unattended units located in an equipment room near CIC. The video generator provides target information and director data appearing on the PPI display of the target designation indicator. The coordinate converter has four channels—one per director. Each channel consists of two sections—one an input section, the other a repeat-back section. The converter receives target information in the form of rectangular coordinates and converts them to polar coordinates, which are transmitted to the directors through the target designation switchboard. (Figure 6C2.) It also converts director data in polar coordinates

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to rectangular coordinates which are transmitted to the video operator for presentation on the PPI display.

The TARGET DESIGNATION SWITCHBOARD contains automatic rotary switches which provide rapid remotely controlled, flexible switching of target designation and director repeat-back circuits. The switches may be operated automatically from the CIC or the AAW station, or manually from the switchboard.

6C7. FROM TARGET DETECTION TO TARGET DESTRUCTION

Let us now trace the entire process from the moment the target is detected until it is destroyed. Bear in mind that there are many details omitted, and that many steps will be different with different ships and equipment. We are assuming for the sake of illustration that a Mk 5 TDS is being used with a Mk 56 GFCS, and that the target information originates with CIC. The entire process is shown graphically in 20 steps in figures 6C6 through 6C16.

TARGET LOCATED BY AAW STATION. When the target has been detected by personnel in the AAW station the procedure differs slightly.

The target is assigned to a port or starboard TDT operator to track. (Figure 6C17.) The TDT operator tracks the target and presses the TDT on-target pushbutton when the target is centered in the binoculars. This illuminates the on-target lamp on the associated control unit. He keeps this pushbutton depressed during the entire time he is tracking.

The operator at the control unit selects the director to receive the designation and turns the director set-up switch on. This sounds a buzzer to inform director personnel of impending designations. The control unit's "busy" indicator lamp for the selected director flashes. The control unit operater positions the "estimated range" switch to the approximate target range, and sets the director repeat-back selector switch to cause director information to appear on the repeat-back dials.

The director officer accepts designation by pressing the target designation pushbutton, which allows the director to slew to the designated coordinates. (Figure 6C18.)

When the radar operator at the radar console has gated the target he presses the footswitch. This shifts the director to automatic tracking, and causes the "tracking" lamp on the control unit to go on.

EMERGENCY OPERATION. If equipment or circuit failure in the radars make normal operation impossible, the Mk 5 TDS can still function to coordinate the target designation operation. By setting a test switch on the video generator so that it develops a "synthetic" trigger pulse (which is normally used in checking and aligning the equipment), the designate and repeat-back hooks can be made to appear on the PPI display. With all hooks properly indicated, even though search radar information is not available, interdirector designation is possible.

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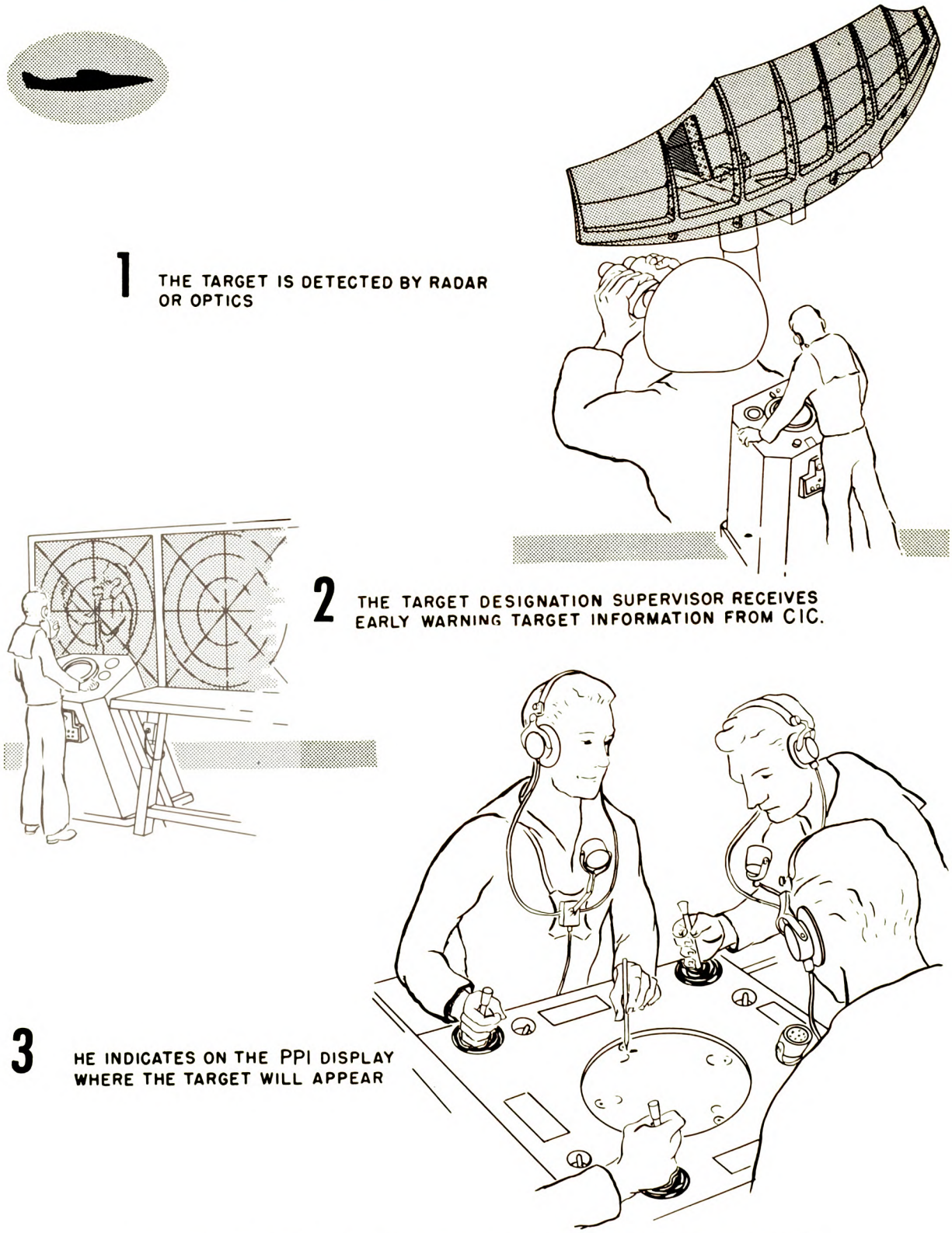

Figure 6C6.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure.

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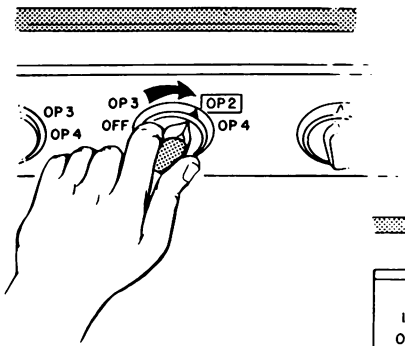
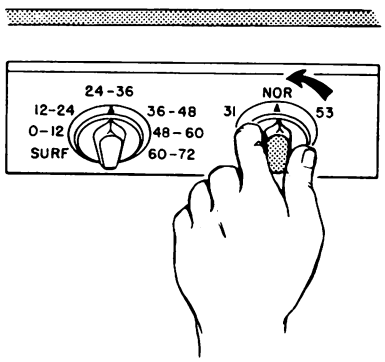
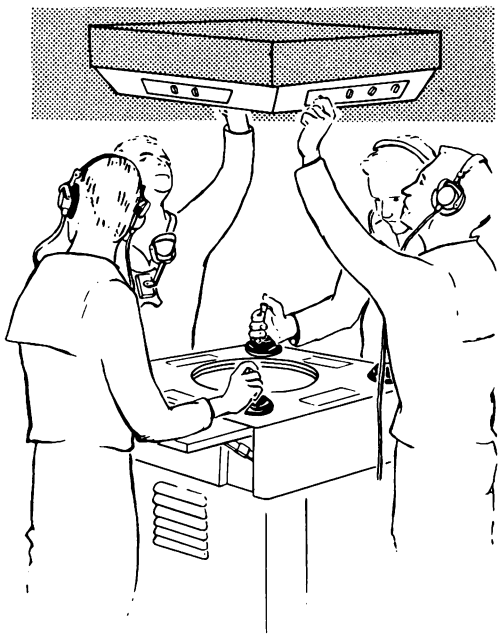
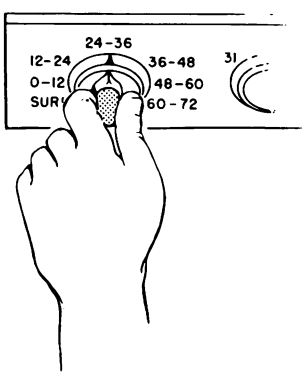
4 THE OPERATOR AND SUPERVISOR POSITION THEIR DIRECTOR SELECTOR SWITCHES.....

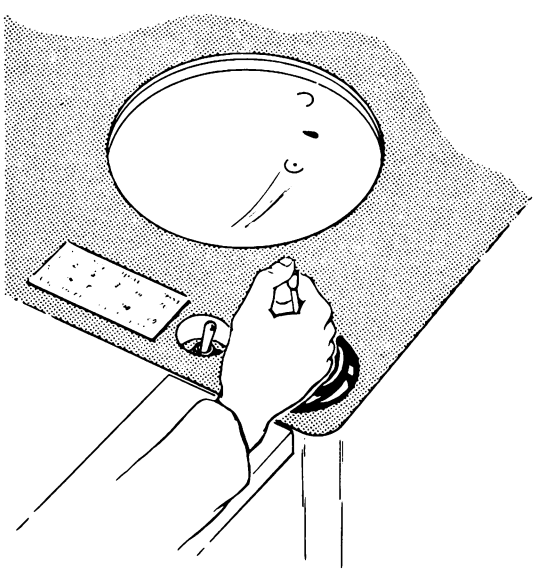






....THE DESIGNATING OPERATOR ALSO POSITIONS THE SIMULATED ELEVATION SWITCH TO THE APPROXIMATE TARGET ELEVATION





5 THE OPERATOR, BY MOVEMENT OF THE JOYSTICK, SLEWS THE DESIGNATE SYMBOL TO THE TARGET AND COMMENCES TRACKING.

....HE THEN POSITIONS THE CALL SWITCH.

Figure 6C7.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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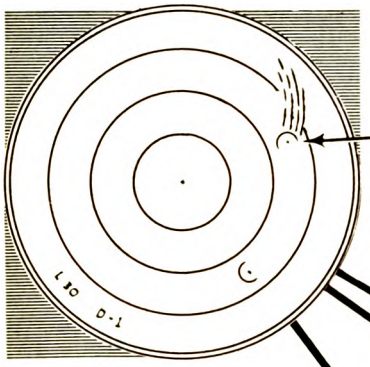
6 **RADAR TRACKER PRESSES TARGET DESIGNATION BUTTON TO ACCEPT DESIGNATION.**



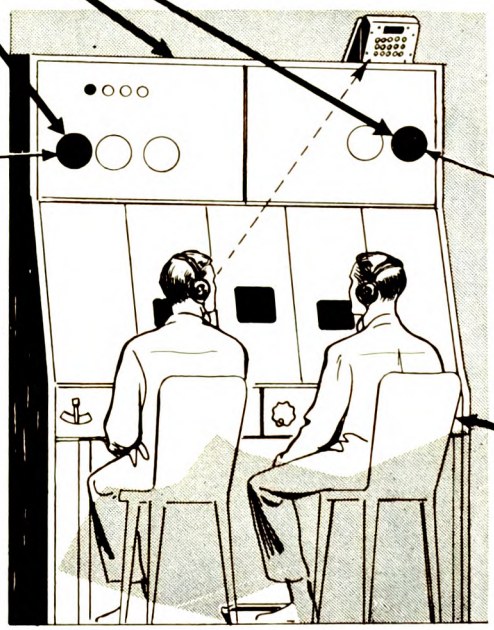
Repeat back hook slews to meet designate hook

Director slews to, and synchronizes with designated bearing and elevation.

Range dial matches designated range pointer.

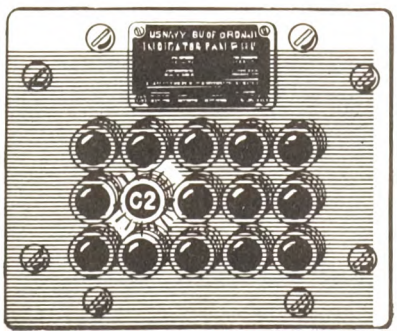
Director train dial matches designated bearing pointer.

RADAR OPERATOR OBSERVES LIGHT ON INDICATOR PANEL MK 5.



Scan control in **SPIRAL**

INDICATOR PANEL MK 5



C2 light indicates that SEARCH RADAR No. 2 is transmitting designation data.

Target designation button

Figure 6C8.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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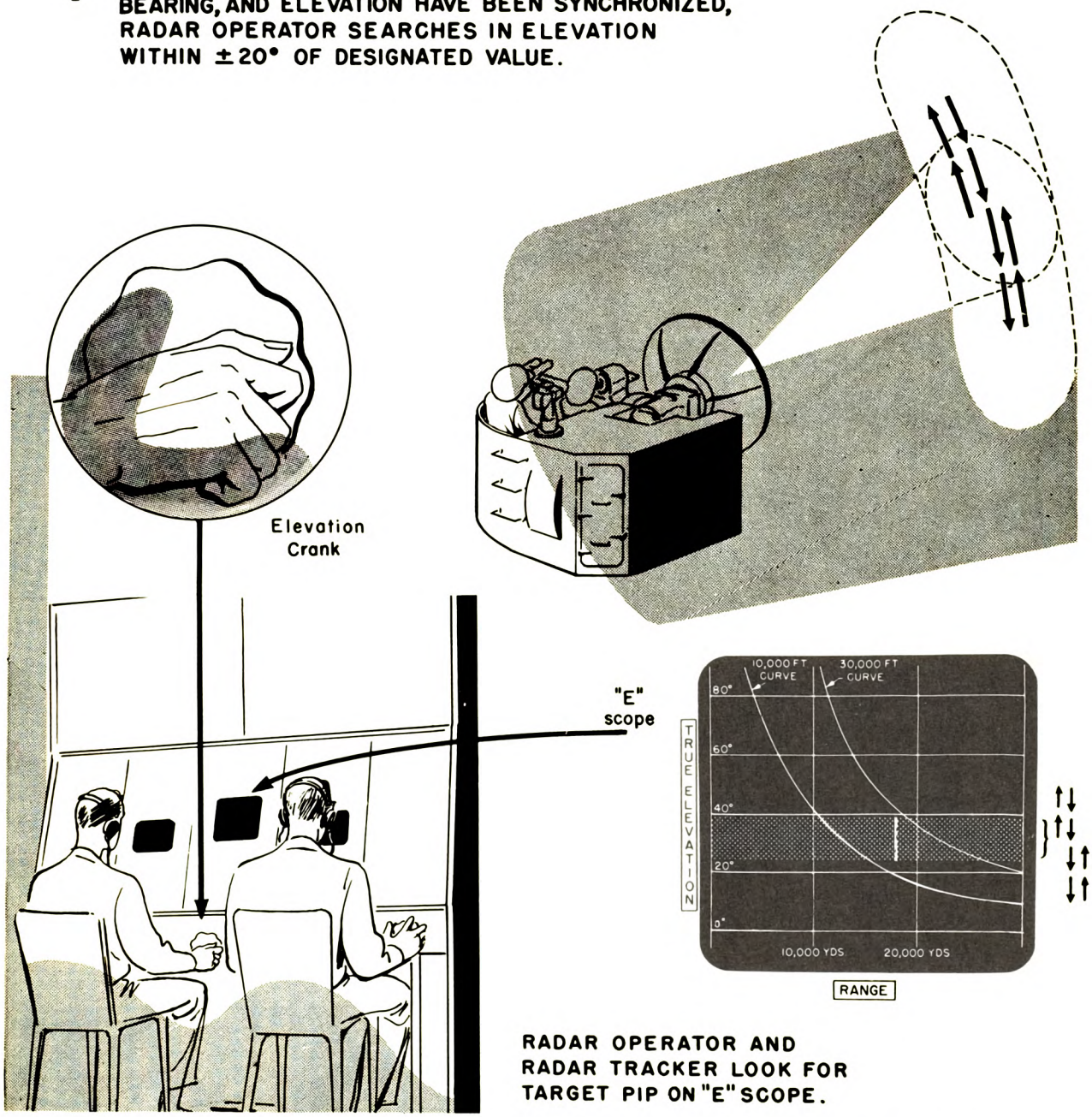
7 IF PIP DOES NOT APPEAR WHEN RANGE, BEARING, AND ELEVATION HAVE BEEN SYNCHRONIZED, RADAR OPERATOR SEARCHES IN ELEVATION WITHIN ±20° OF DESIGNATED VALUE.



RADAR OPERATOR AND RADAR TRACKER LOOK FOR TARGET PIP ON "E" SCOPE.

8 IF PIP DOES NOT APPEAR DURING ELEVATION SEARCH, RADAR TRACKER SEARCHES WITHIN ±20° OF DESIGNATED BEARING.

9 IF PIP DOES NOT APPEAR DURING BEARING SEARCH, RADAR TRACKER PRESSES "SEARCH ERASE" BUTTON TO RE-SYNCHRONIZE SYSTEM. THEN BOTH OPERATORS REPEAT ELEVATION AND BEARING SEARCHES.

Figure 6C9.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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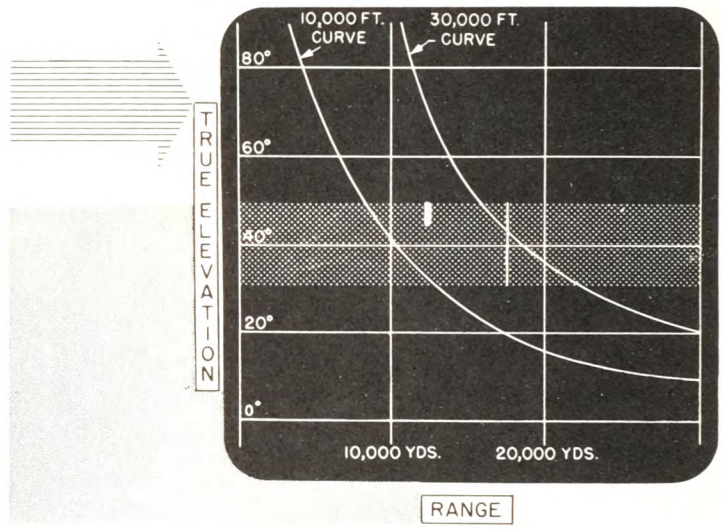
10 WHEN TARGET PIP IS VISIBLE ON "E" SCOPE . . .

. . . OPERATORS STOP SEARCHING; THEN . . .



11 . . . RADAR OPERATOR . . .

A . . . SLEWS RANGE MARK CLOSE TO TARGET PIP, AND . . .

B . . . CRANKS ELEVATION TO CENTER PIP ON TRACE.

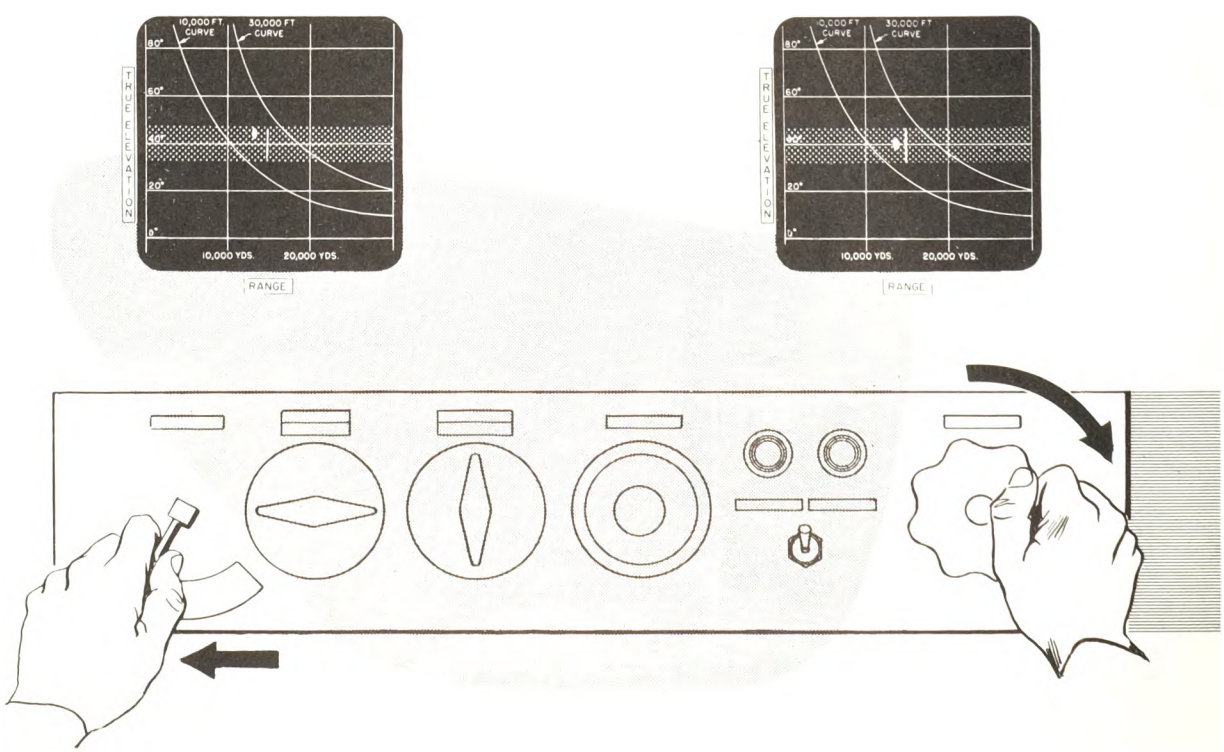


Figure 6C10.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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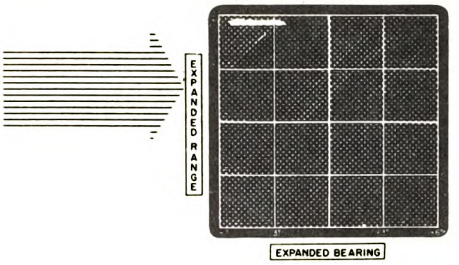
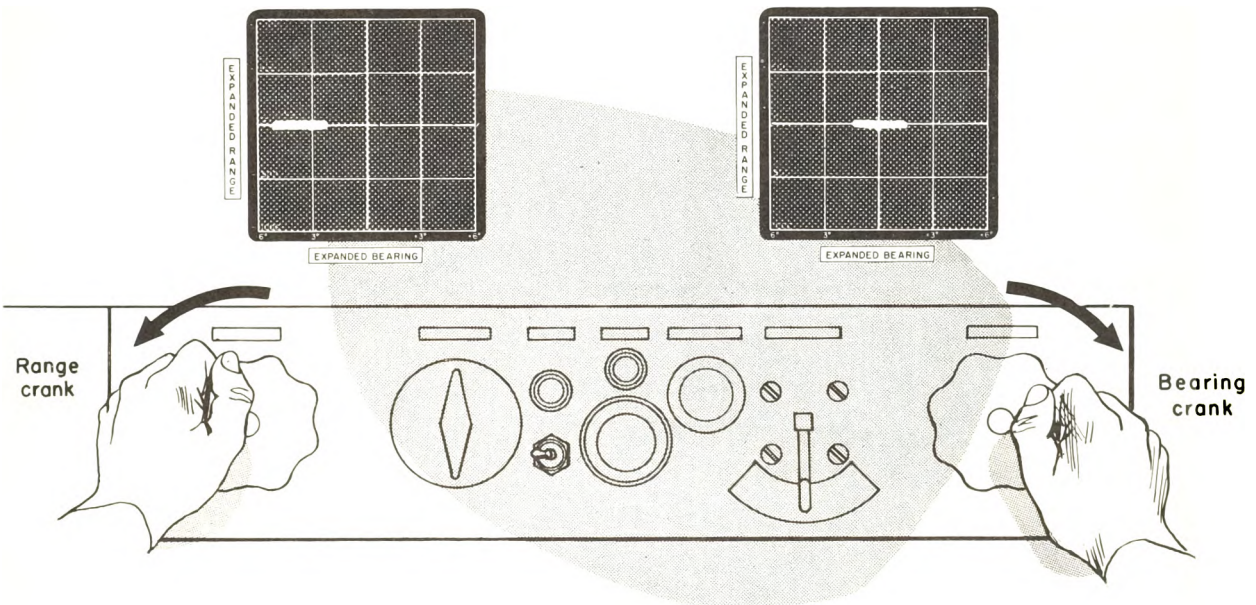
12 AS SOON AS PIP IS VISIBLE ON "B" SCOPE . . .



. . . RADAR TRACKER . . .

A . . . CRANKS RANGE TO CENTER PIP VERTICALLY, AND . . .

B . . . CRANKS BEARING TO CENTER PIP HORIZONTALLY; THEN . . .



13 . . . PRESSES SCAN CONTROL **FOOT SWITCH** TO SHIFT TO **CONICAL** SCAN FOR AUTOMATIC RADAR TRACKING

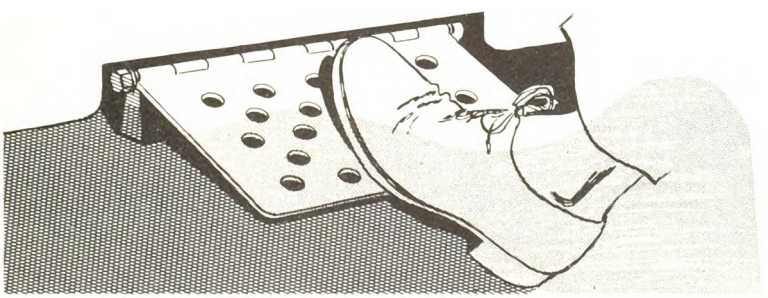


Figure 6C11.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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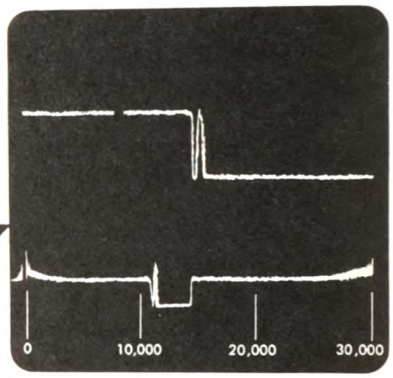
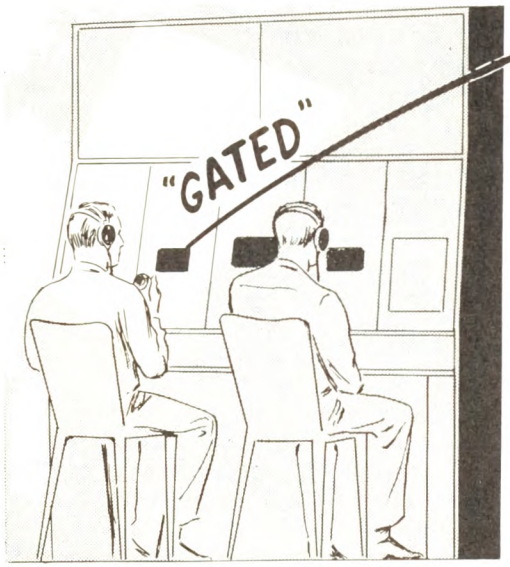
14 WHEN TRACKING CIRCUITS "LOCK ON" PIP...



"A/R" scope

... RADAR OPERATOR REPORTS...



... TO CONTROL OFFICER.

15 CONTROL OFFICER ORDERS...

..."MOUNT 52 ... MATCH POINTERS AND SHIFT TO AUTOMATIC"

HAND MICROPHONE

16 DIRECTOR OPERATOR RELAYS MOUNT CAPTAIN'S REPORT OF "MOUNT 52 IN AUTO" TO CONTROL OFFICER THROUGH VOICE TUBE.

Figure 6C12.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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17 AUTOMATIC RADAR TRACKING—

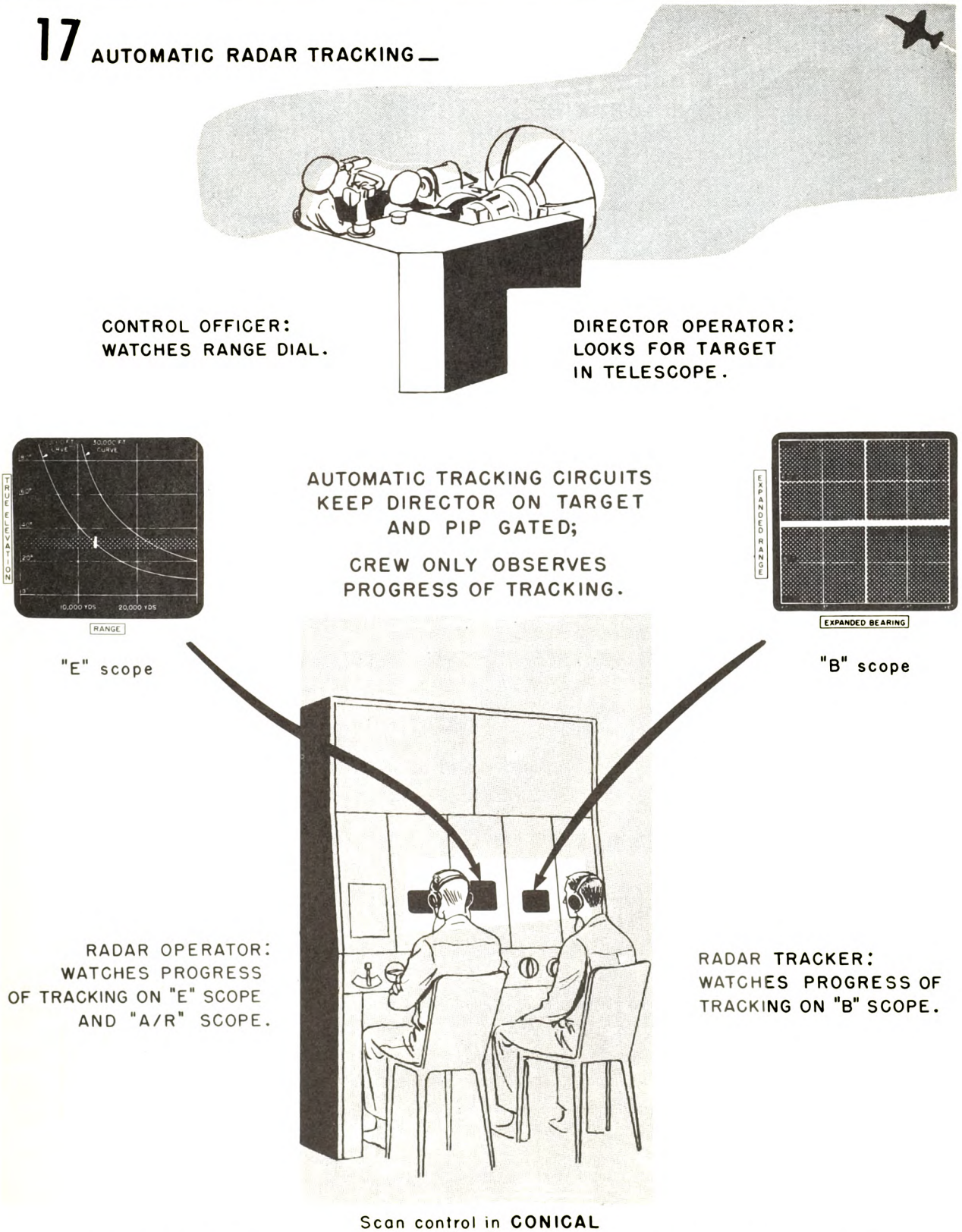

Figure 6C13.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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18 WHEN "OPEN FIRE" RANGE IS REACHED, CONTROL OFFICER ORDERS...

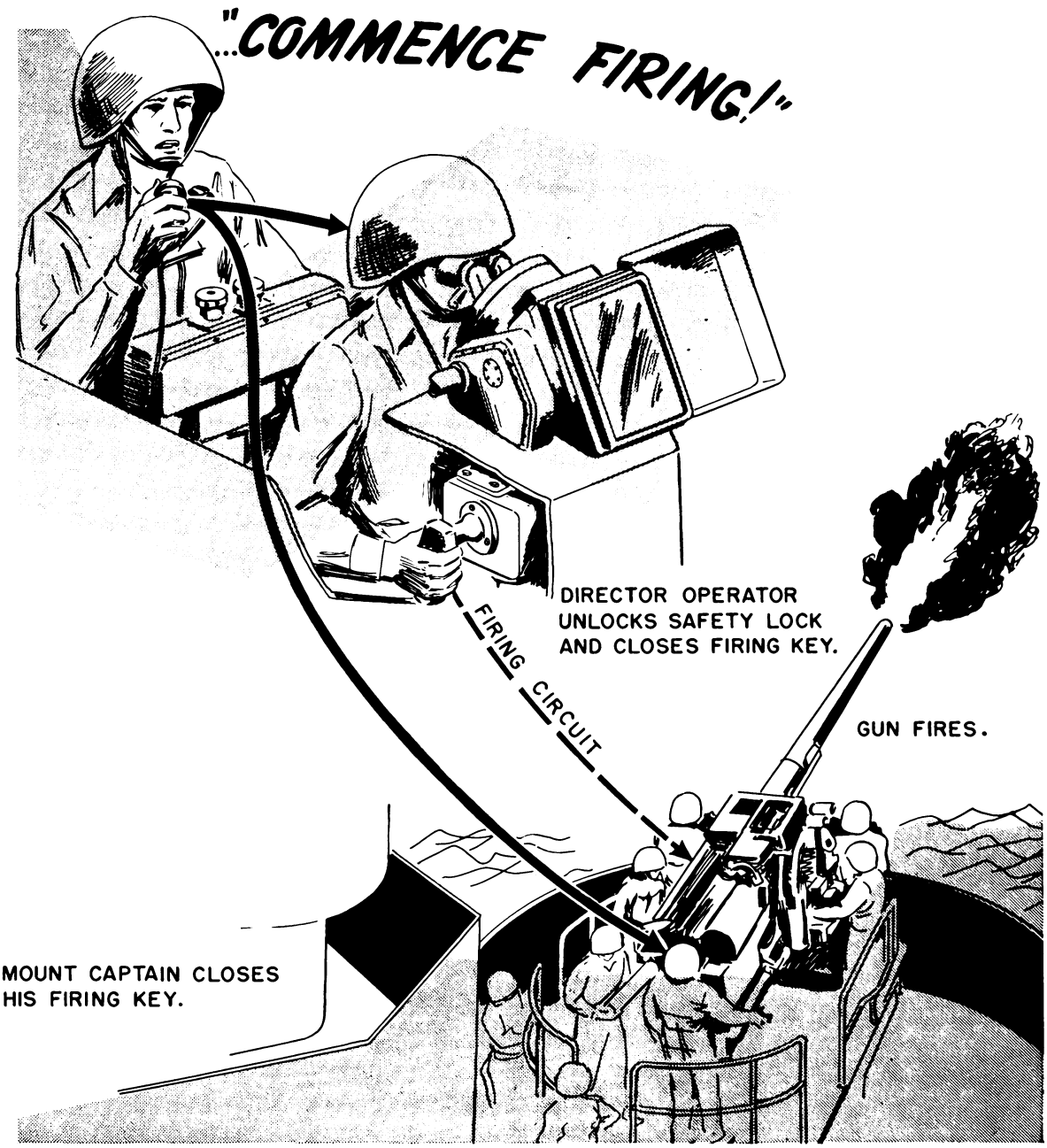

Figure 6C14.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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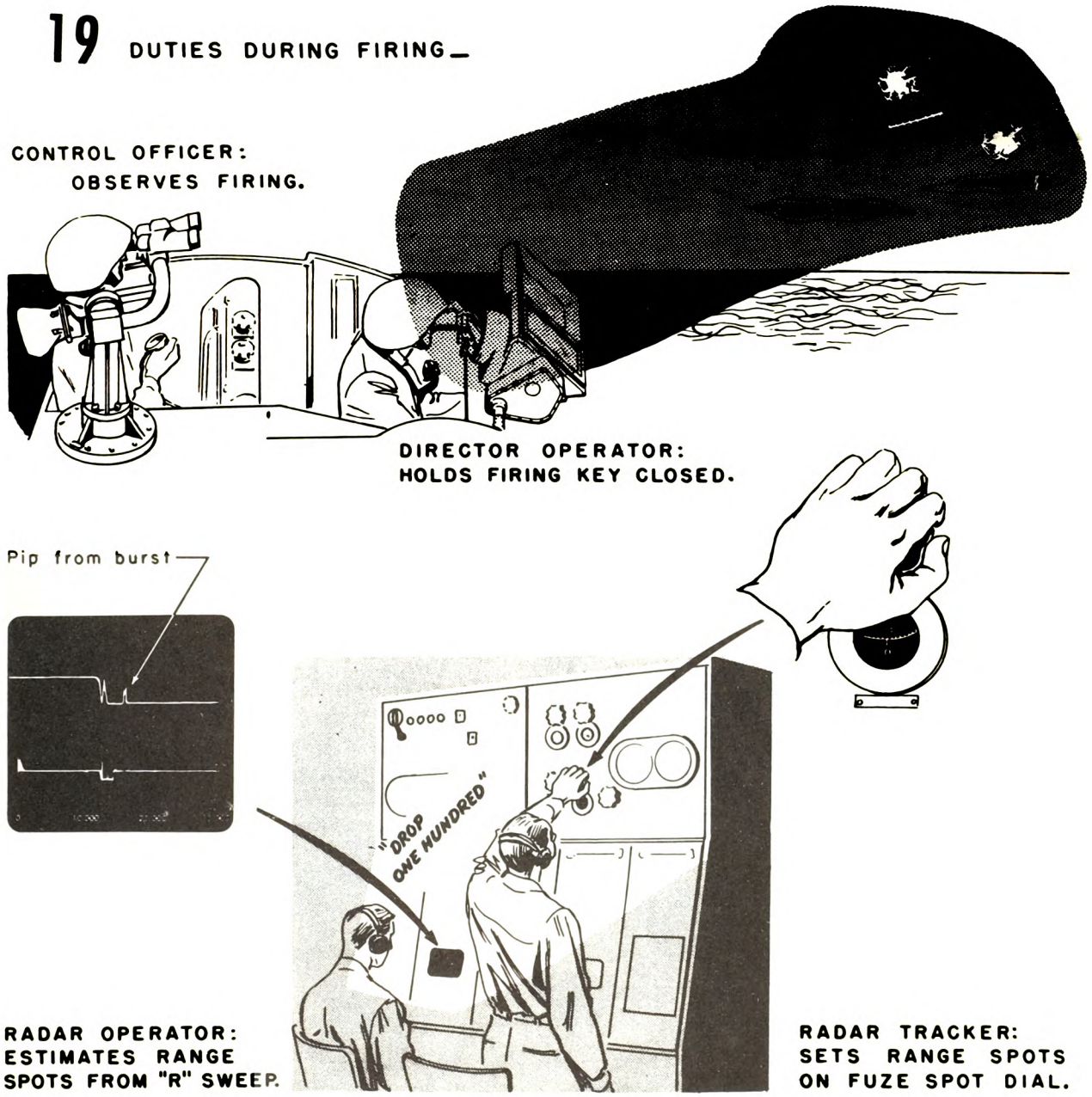

ELEVATION AND DEFLECTION SPOTS MAY BE ESTIMATED FROM "E" AND "B" SCOPES AND INTRODUCED ON ANGLE SPOT TRANSMITTER.

ALL SPOTTING SUBJECT TO SHIP'S DOCTRINE.

Figure 6C15.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Continued.

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20 WHEN CONTROL OFFICER OBSERVES THAT TARGET IS DESTROYED OR HAS PASSED BEYOND EFFECTIVE FIRING RANGE, HE PULLS CEASE FIRING HANDLE AND ORDERS...

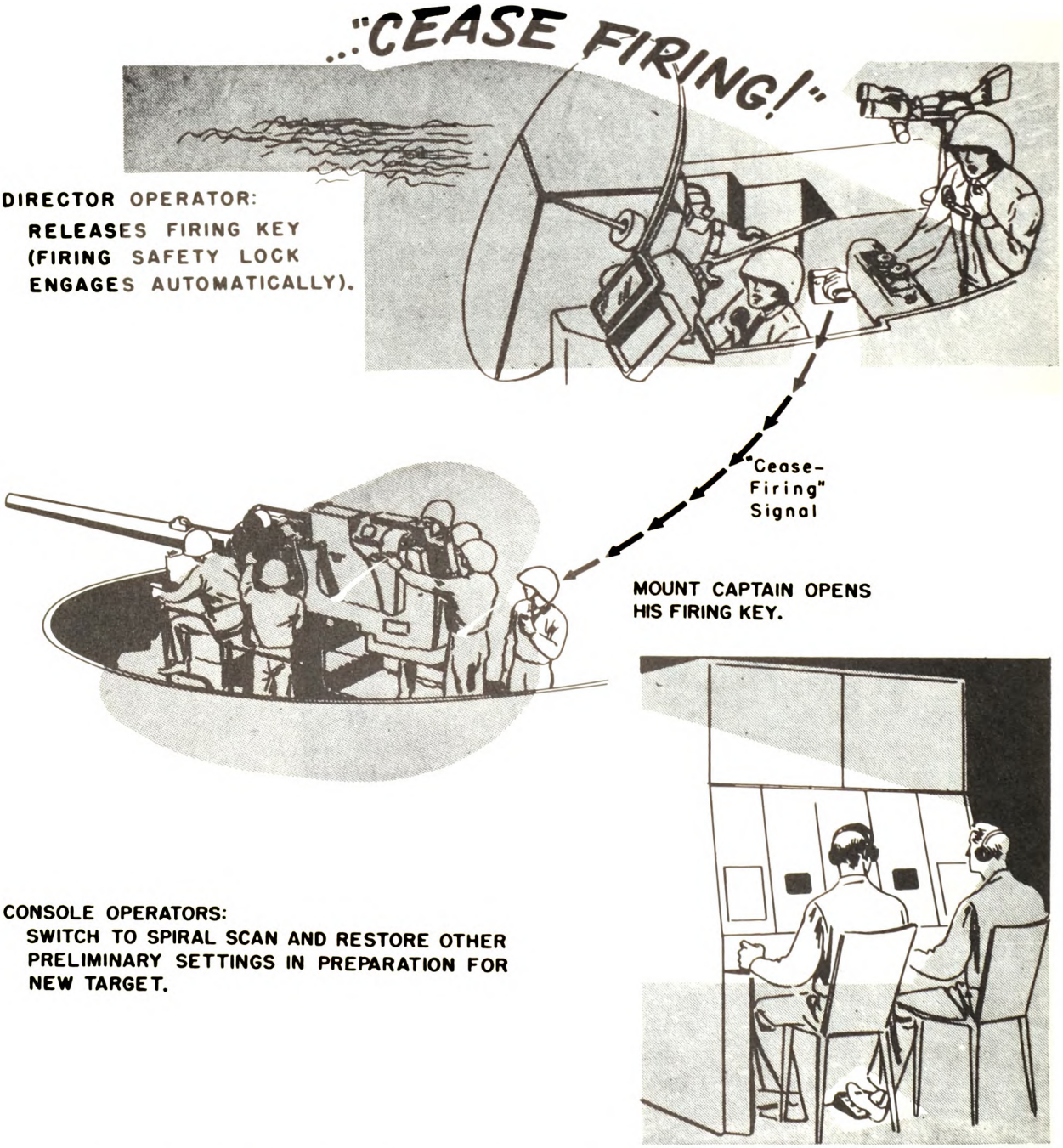

Figure 6C16.—Mk 5 TDS. Steps in target designation, acquisition, tracking, and attack procedure—Concluded.

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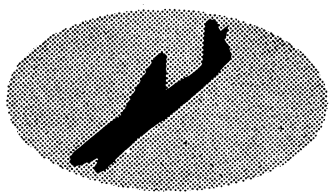
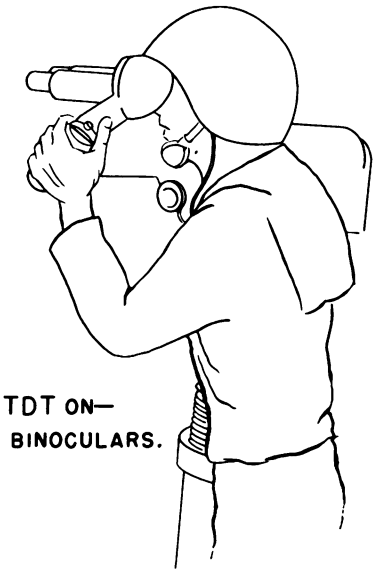


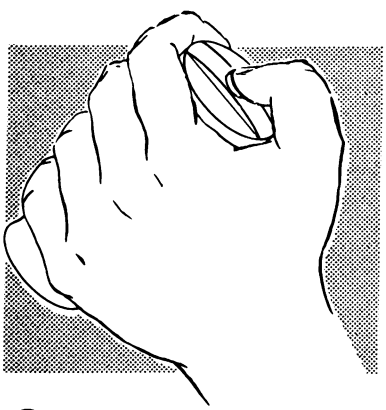
1

THE TARGET IS DETECTED BY PERSONNEL IN THE AAW STATION AND ASSIGNED TO A TDT OPERATOR TO TRACK.



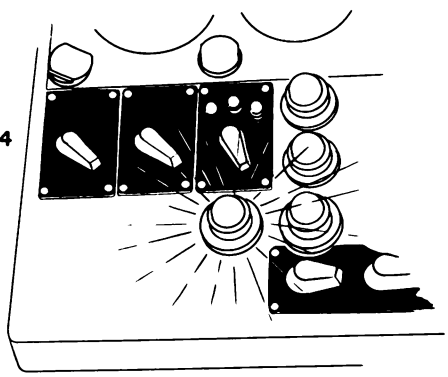
2

THE TDT OPERATOR TRACKS THE TARGET AND PRESSES THE TDT ON-TARGET PUSHBUTTON WHEN THE TARGET IS CENTERED IN THE BINOCULARS.



. . . . WHICH

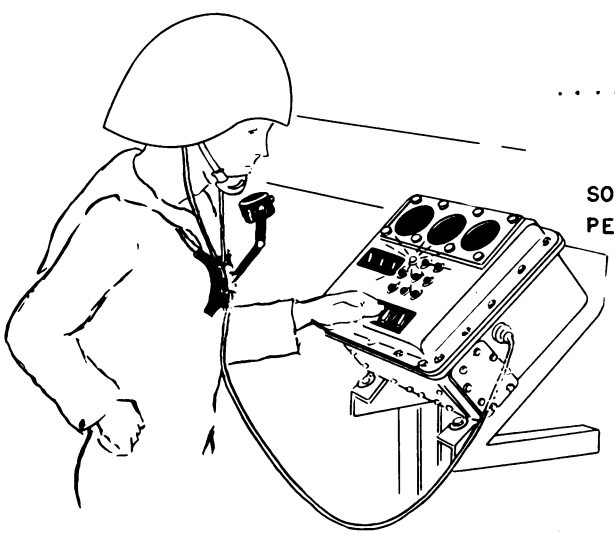
ILLUMINATES THE ON-TARGET LAMP ON CONTROL UNIT MK 74



3

THE OPERATOR AT THE CONTROL SELECTS THE DIRECTOR TO RECEIVE THE DESIGNATION AND POSITIONS THE DIRECTOR SET-UP SWITCH TO ON

. . . . THIS



SOUNDS A BUZZER INFORMING GUN FIRE CONTROL SYSTEM PERSONNEL OF IMPENDING DESIGNATIONS.

. . . THE BUSY OR OWN CONT. LAMP OF THE SELECTED DIRECTOR FLASHES

Figures 6C17.—Mk 5 TDS steps in target designation procedure (AAW station). 110.79.1

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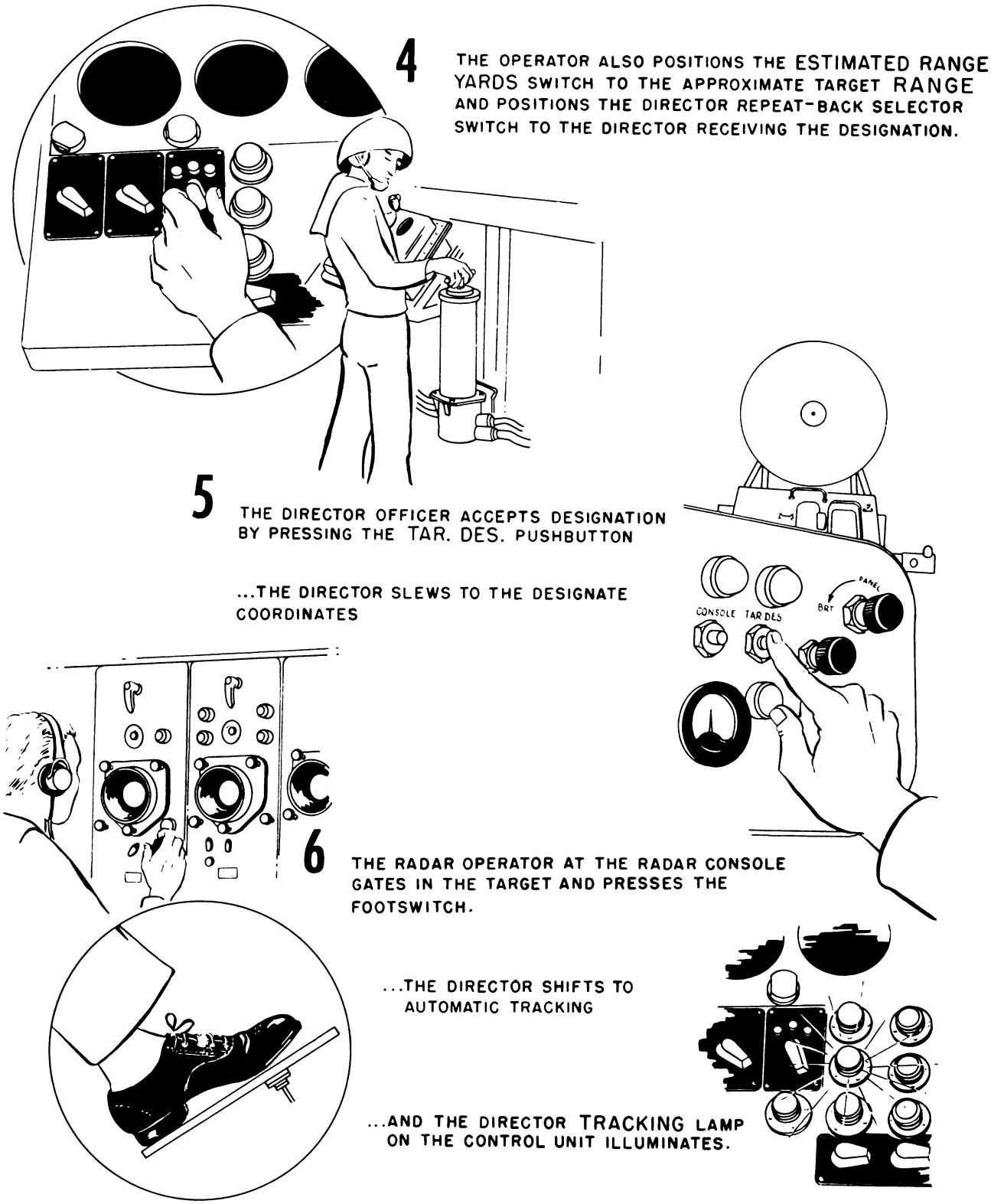

110.79.2

Figure 6C18.—Mk 5 TDS steps in target designation procedure (AAW station).—Continued

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D. Director Assignment with a WDS

6D1. INTRODUCTION

A WDS is basically a TDS. It is more sophisticated since more stations and electronic components are involved, and since a WDS controls both missile and gun fire control systems. You'll notice major refinements, particularly in the areas of director assignment and CIC tracking prior to director assignment. One PPI-scope did these jobs in the TDS; approximately four separate consoles are used in the WDS. Three of these consoles (those used to track targets prior to director assignment) are called Target Selection and Tracking Consoles (TSTC). The other console is used to make director assignments and is appropriately named the Director Assignment Console (DAC).

A WDS includes all electronic and optical devices used in designating targets. The optical devices are TDTs in the AAW station(s) whose operation we have previously discussed. The electronic devices are all part of a sub-equipment called the Weapons Direction Equipment (WDE). A WDE has as its major units the four consoles mentioned above and another console called the Weapon Assignment Console (WAC). The WAC has no designating function. Its purpose is to provide a means for assigning the missile launcher (an act which is similar to putting guns into automatic) and to fire the missile at the optimum time.

6D2. GENERAL DESCRIPTION OF A WDS

Don't be dismayed by the abbreviations in the preceding article. They will become commonplace if you are assigned to the weapons department of a missile ship where these terms (and their abbreviations) are used.

Figure 6D1 shows the major units in a WDS that are used in radar designations (some were eliminated for simplicity). Notice that a missile fire control director and its computer, and gun fire control director and its computer, are depicted along with their respective delivery devices; i.e., a missile launcher and a gun. You'll recall that once a target is acquired by a fire control system, the system functions independently of the WDS in tracking the target, and in computing the launcher or gun orders. The function of the WDS, then, is to direct the fire control system to the target initially.

An air search radar detects targets and sends the video data simultaneously to three TSTCs. The TSTC in CIC selects the targets to be tracked by the other two TSTCs in the weapons control station. This is done by assigning electronic tracking channels to the targets. A tracking channel is assigned to a target based on evaluation by the CIC evaluator and the WLO. Each TSTC operator in the weapons control station has a prearranged responsibility for establishing a track in one-half of the total number of channels—a division of the tracking load results. A target movement rate is electronically available within a channel after a few seconds of manual operation by a TSTC operator. The established rate enables the TSTC to track the target automatically as long as relative motion factors are constant. Additional minor corrections are required by the operator if the relative motion factors vary. Tracking channel data are sent automatically to the director assignment console. These data include range, bearing, course, speed, altitude, and estimated weapon release range for as many targets as are being tracked. The system can track as many targets as the number of tracking channels permits.

It is from the director assignment console (where all target data are collected and displayed) that a specific director or fire control system is selected to destroy the target. The selected director slews (i.e., moves at an accelerated rate) to the target's present position in range, bearing, and elevation. If all equipment is aligned and functioning properly, the target echo is now visible on the fire control system's radarscopes. The crew refines director position and causes the fire control system to shift into automatic radar track. When a system shifts into automatic track its associated computer starts computing precise gun or launcher orders. Synchronizing a gun to its ordered position, and its subsequent loading and firing are processes that are controlled by the system's director officer. Loading a launcher, synchronizing it, and firing the missile are steps that are supervised by the WAC operator (nominally, the missile officer). Control doctrine normally requires these officers to receive orders from the ship's weapons officer before firing ordnance.

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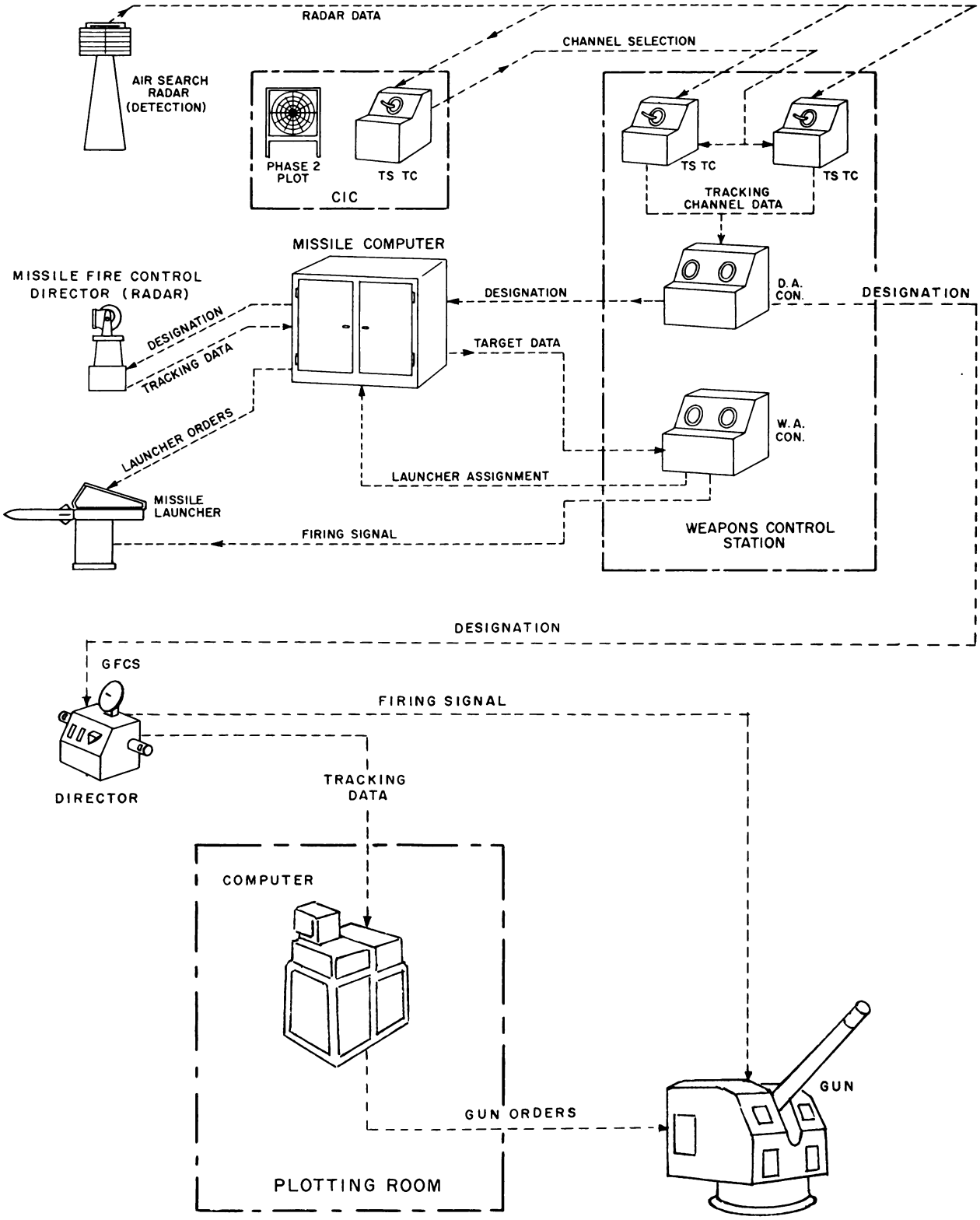

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Figure 6D1.—WDS simplified data flow.

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We'll now take a closer look at the operation of a TSTC, and in the following article, a DAC. The WAC will be covered in the second volume of this series. Even though figure 6D1 is representative, it does not show the exact number of WDS units installed on all missile ships. The number (and the location) of these units depends on the ship's armament.

6D3. THE TARGET SELECTION AND TRACKING CONSOLE

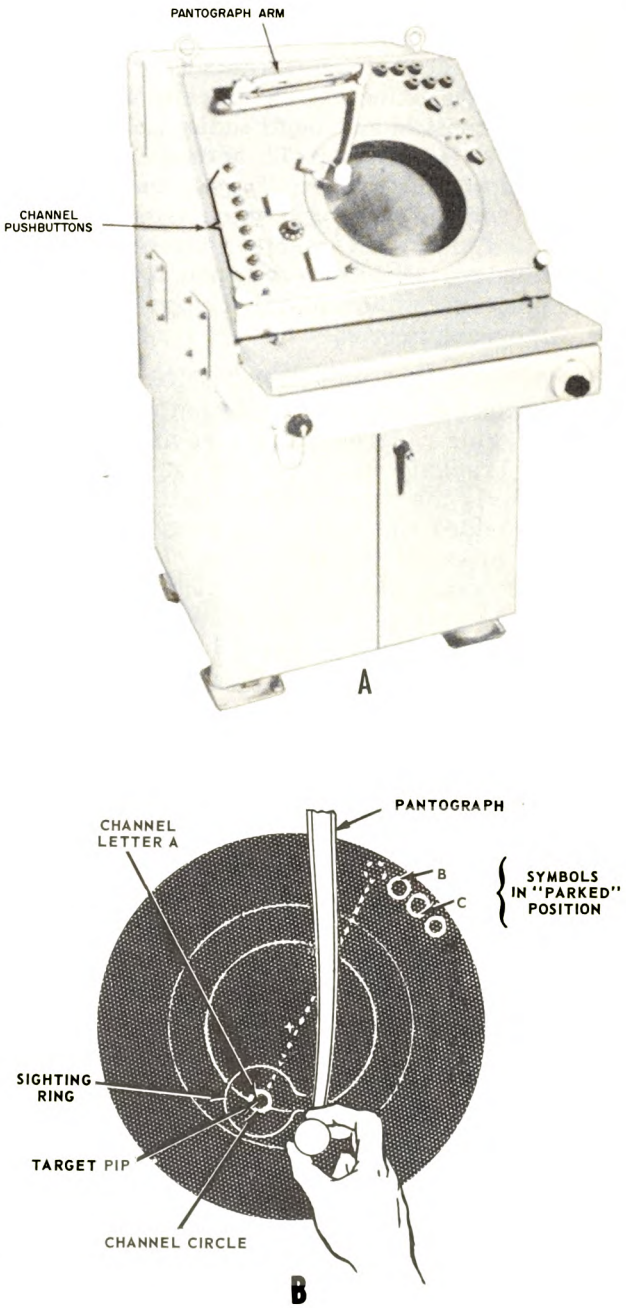
There is a typical TSTC and its PPI display in figure 6D2. If this were the one in CIC, it would be controlled by an assigned operator who is under the direct supervision of the WLO. The console displays targets on a PPI presentation which can be shifted to monitor various radar search displays. Shifting of the radar display permits system flexibility in the event of malfunction or poor reception of any one search radar. If the air search radars are equally receptive, the console operator will select one that has a height-finding capability and the narrowest radar beam.

As mentioned previously, the target height quantity is eventually converted into an angle of true target elevation for use by the directors. We observed that this eliminated large sector searching in elevation by the directors and therefore greatly reduced target acquisition time.

Using the search radar that has the narrowest beam further reduces target acquisition time in that it more definitively pinpoints the target's position. Search radars have a much larger beam width than fire control radars. This means that a certain amount of refining or searching by the fire control director is required after it has been designated to a target by a relatively broad beam search radar. Correct radar alignment reduces the searching requirement.

Any one of the three consoles can be used to send target data to the DAC. In practice the WLO's TSTC is used to alert the other two to the threat of an attack. That is, the WLO's console will select the target to be tracked and the other two consoles will do the actual tracking.

Target selection is accomplished by placing the pantograph arm on the console directly over the target video on the radarscope. A small illuminated dot, which represents the position of the pantograph arm, will then be superimposed on the target video. If evaluation indicates that the contact is a threat, the WLO will order his console operator to assign a tracking channel to the target.



12.42

Figure 6D2.—A. typical target selection and tracking console; B. TSTC display.

There are a number of tracking channels in this equipment. Several tracking channels are

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necessary in order to separate the movement data of one target from another when the console is used to track multiple targets. Buttons which activate the tracking channels are located on the left of the console and identified by single letters such as A, B, C, etc. To activate a tracking channel for a particular bogey, the operator presses a channel button which is not in use. A small illuminated circle with the channel letter designator within will then appear in the same position on the radarscope as the dot from the pantograph arm.

The two target selection and tracking consoles in the weapons control station have more or less the same radarscope picture as the console in CIC. Tracking channel C for example, shows up in exactly the same position on all three consoles provided the individual console controls are set alike. Disparities in console presentations occur when different range scales or radars are selected by the console operators. However, the true position of both the symbols and targets is unaffected by the console controls.

To reiterate, the presence of a tracking channel symbol superimposed on target video will cause the tracking operators to commence tracking that particular target. Upon assigning a channel to a target, the console operator in CIC parallels visible information via sound-powered telephones. It is in this way that the WLO can select the target to be tracked by weapons control.

The evaluator or WLO estimates the target's weapon release range and the console operator manually inserts it into the system. Insertion of EWRR (estimated weapon release range) is accomplished at the WLO's console by pressing the appropriate channel button and simultaneously making the input at an attached panel. This channel circuit activating prerequisite permits each tracking channel to have its own EWRR. Knowing the target's EWRR aids weapons control in making a director-to-target assignment. This is particularly true if multiple targets have been detected.

Pre-battle intelligence relating to the enemy's aircraft types and weapon capabilities should be available to the evaluator. Studies will have to be made, based on all available information, to provide EWRRs for different aircraft types. Standards will have to be developed for use in the absence of target amplifying data. The evaluator, who is a very busy individual, may delegate the determination of EWRR to the WLO. In any event, the WLO is responsible for its insertion into the equipment.

WDE designation-accept circuitry has no way of knowing automatically which search radar is being used by the target selection and tracking consoles. This presents a problem when search radars without height-finding capabilities are the source for target designation. Obviously, target height data in this case are unreliable. Some means is then necessary to inform control personnel and increase the limits of the fire control directors' elevation search arcs. A switch, activated by a target selection and tracking console operator, will illuminate "elevation unreliable" lights throughout the system. The same switch triggers computers which then enlarge elevation search in missile directors during the acquisition phase. Throwing this switch is unnecessary on destroyers because the absence of height data automatically activates elevation unreliable circuits.

We mentioned before that the WLO selects the target to be tracked by weapons control. Actually his is a mechanical selection which is an execution of the evaluator's tactical selection. In the heat and confusion of battle, however, these two individuals may often find their responsibilities overlapping. It is mandatory that the evaluator and WLO work together as a team. The WLO will sometimes be required to take control of weapon direction when the evaluator is involved in another facet of this extremely complex battle station. An alert WLO may observe a threat on his radarscope that is not displayed on the phase 2 plot. He can also anticipate the evaluator's decision and assign inactive tracking channels to suspected threats. This does not mean it is time to start shooting. The WLO is merely establishing a TS and TC track on the contact.

Tracking at the target selection and tracking consoles is rate-aided. That is, a target movement rate is established which subsequently aids the operator in tracking. The rate is generated by repositioning the pantograph arm to coincide with the target's movement. When the pantograph arm is moved, and a rate-aid switch is activated, present target position data are inserted into the tracking channel. Successive changes of pantograph position are electronically compared with previous positions and a target rate is the eventual result. The continuous rate-aided solution will then keep the channel letter designator positioned on target. Three or four pantograph corrections should be all that are needed to establish a fairly accurate rate.

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Minor corrections are necessary as the track progresses to compensate for changes in target course, attitude, or speed. Rate-aided tracking pays off since multiple targets can be tracked with one tracking console using one pantograph device.

The operators of the two tracking consoles in WCS are responsible for tracking in channels to which they have been assigned. The practice is to assign half of the channels to each operator. It is then up to the selecting console in CIC to split up the tracking load. A tracking operator can insert target data into a channel only if he has access to that channel. We are speaking now of electronic access and not predetermined responsibility. Channel access is electronically indicated by the presence of a small circle around the channel letter designator on the radarscope. A tracking console operator can gain access to a channel through a switch on the pantograph arm or by pressing the desired channel pushbutton.

It is possible to display access circles for a particular channel on more than one console and for more than one operator to make alternate corrections to the channel's rate. It is not possible for more than one operator to make rate corrections simultaneously in that particular channel. In the event simultaneous inputs are attempted, an electrical order of precedence takes over and permits the channel to receive data from one source only. The console with the highest precedence is understandably in CIC. Precedence is also established for the two consoles in WCS.

Target height or altitude graduations are inscribed toward the left on the radarscope of each target selection and tracking console. These graduations or indices increase from bottom to top on the scope with each increment equal to 5000 feet. If a 3-coordinate radar has been selected at the console, a video dot representing the target's height will appear adjacent to the height graduations. The video dot moves vertically in response to target height information from the radar. Target height is then visually apparent to the operator when he compares the dot's vertical position to the inscribed indices.

To put height into a channel, the operator gains access, rotates a height cursor knob to align a height measuring spot on the scope to the vertical position of the video dot, and then operates a "height data in" switch that stores height into the channel. If a 3-coordinate radar is unavailable, the equipment can continue to send height data to the WCS provided height has been received in a GEOREF report. The known height data are substituted for the vertical position of the video dot. The height cursor knob is rotated until the measuring spot agrees with the reported height and the rest of the operation remains the same. Height data from another ship are not as accurate as that received from our own ship's radar; therefore the console operator throws a switch that energizes the "elevation unreliable" circuits, except for destroyers where this is unnecessary.

6D4. THE DIRECTOR ASSIGNMENT CONSOLE

Assigning the proper director in time is very important in AAW. The officer operating the director assignment console must be extremely well qualified. He must be aware of tactical considerations, and be able to comprehend the electronic difficulties which sometimes beset this very complicated equipment. His electronic knowledge must extend to all phases of director assignment and the director's ability to receive designations.

Tracking data from a channel are fed automatically from the tracking console into the director assignment console. Two plots or scopes are provided on this console. They are called the plan and multipurpose plots. (See fig. 6D3.) Target video is not present on these plots, but the plan plot shows target range and bearing by displaying the same channel letter designators we have discussed before. Target course and speed for a particular channel can be approximated on the plan plot by a vector which has its tail attached to the channel letter. The vector's magnitude and direction correspond to target speed and course. (See channel A in plan plot.)

Numbers which show the range and bearing of the directors are also displayed on the plan plot. The director numbers are always present, but a channel letter shows up only when that channel is used to track a target. All of the symbols (numbers and letters) are intensity modulated; that is, they show up on the scope as a video presentation. The directors are numbered in increasing numerical order from forward to aft on the ship. All directors that are used in AAW have their numbers displayed on the director assignment console. The director numbers are also displayed on the target selection and tracking consoles provided the director is tracking If director 1 is tracking channel B, a 1 would be superimposed on the B.

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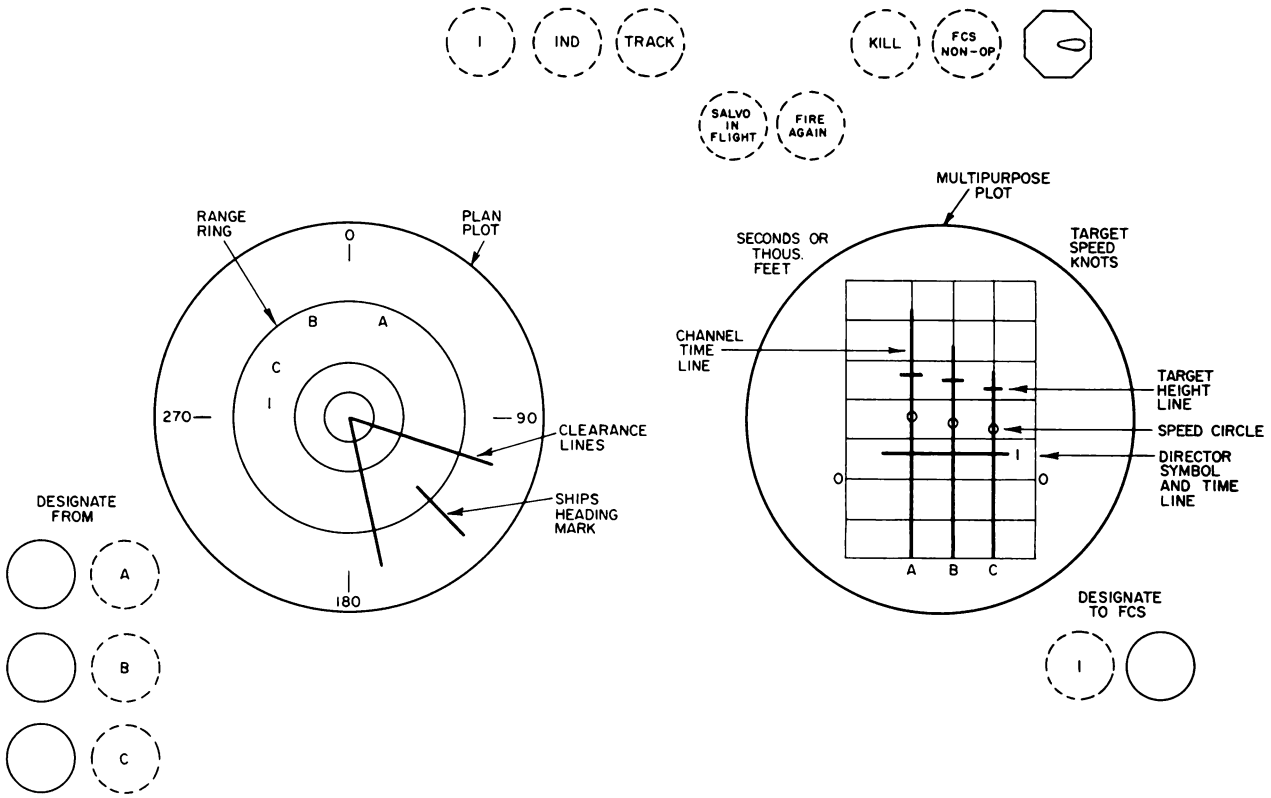

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Figure 6D3.—Director assignment console display.

The plan plot also presents a ship's heading mark, which is a continuous indication of own ship's course. There is a radial line on each side of the heading mark that also moves in response to course changes. The arc described between the radial lines through the ship's head marker represents the missile blind zone for an after launcher installation.

The multipurpose plot is used for making time comparisons which enable the operator to select one of several targets for designation to a director. This plot permits the operator to plan ahead in case the directors are occupied and cannot be assigned immediately. Target height and speed are also displayed on this plot to aid the operator in director assignment.

The multipurpose plot has a vertical video line for each tracking channel. The vertical length or height of the line is compared to inscribed indices on the scope which represent time. The vertical time lines are "programmed" to show when a director must be designated to a particular channel, so that a missile may be fired to intercept before the target reaches his estimated weapon release range. The factors which affect the height of the vertical line are target range and speed, fire control director acquisition time, weapon assignment time, and EWRR. Computations for these lines are based upon their application to missile fire control systems; however, approximations can be made which will apply to gunnery fire control systems as well.

Pushbuttons on the left side of the director assignment console are used to "designate from" a target data source. The source may be any one of the tracking channels, one of the optical target designation transmitters (TDTs), or one of the AAW directors which has previously acquired the target. Your ship may have two or four TDTs located at topside AAW

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station(s). TDTs are used to designate targets which may have escaped radar detection. Designating from a director to another director is called interdirector designation; it is by far the most expeditious method, since the target is more accurately pinpointed by fire control radar.

Pushbuttons on the right side of the console are used to "designate to" a fire control system. There is a pushbutton for each AAW director arranged in numerical order from top to bottom on the console.

To assign a director to a target data source, the console operator merely presses a "designate from" simultaneously with a "designate to" push button. For example, if we wish director 1 to track the target in channel C, we would depress the C in the "designate from" column and the 1 in the "designate to" column simultaneously. If we want director 1 to track director 2's target, we would depress the 2 in "designate from" along with the 1 in "designate to." (The total number of directors and data sources is not shown in fig. 6D3.)

Circuits are then activated which automatically slew the director to the target in range, bearing, and elevation. Remember, the accuracy of the elevation information depends on the reliability of target height data. Range and bearing accuracy depends primarily on the tracking ability of the target selection and tracking console operator. We are assuming that your equipment is aligned and functioning properly.

A director is released from designation when it "sees" the target with its own equipment or when the DAC operator presses a designation "release" pushbutton on the right side of the console. The "release" pushbutton will have to be depressed at the same time as the director's "designation to" pushbutton.

A tracking channel is "dumped" by using more or less the same procedure. Another release button, on the lower left of the console, must be depressed simultaneously with the pushbutton for the channel that is no longer desired. A tracking channel can also be dumped at the target selection and tracking consoles by using the same procedure; however, a good practice would be to dump channels only from the director assignment console. Undesirable accelerated movement at the director may result if a channel is dumped when the director is attempting to acquire the target. For this reason it seems advisable to dump channels from the DAC, since it is the only console where director acquisition of the target can be viewed. As you will recall, the director's number is not present on the target selection and tracking consoles until the director shifts into the track mode.

An ever-present problem in weaponry is the limitation placed upon firing arcs by the ship's superstructure. For obvious reasons, launchers and guns are electrically cut out if they are aimed at any part of the ship. The cutout area in bearing and elevation is referred to as the blind zone for a specific weapon. An after launcher cannot fire dead ahead and a forward gun is cut out directly aft. The blind zone problem is still present even when similar weapons are located fore and aft, provided an attack is overloaded in one direction. The director assignment console operator solves this problem by making course recommendations to the pilot house. Maximum fire power will be brought to bear if the ship places her beam to the expected attack, however, this is not always feasible. To recommend a course, the director assignment console operator rotates a "course recommend" knob to the desired course, activates a "course recmd" switch, and an electrical signal positions a course indicator in the pilot house. Course recommendations are paralleled via the JA telephone circuit for general information and to give the officer of the deck an opportunity to intercede if the new course would endanger the ship. In making course recommendations, the DAC operator must consider the dead time before a steering order is given and the time it takes the ship to complete the maneuver. A course is recommended generally as soon as the target's projected track indicates that he will enter the blind zone.

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CHAPTER 7

INTRODUCTION TO GUN BATTERY ALIGNMENT

A. Introduction

7A1. PURPOSE AND SCOPE OF THIS CHAPTER

This chapter takes up the elements of gun battery alignment, explaining the principal operations required in aligning the equipment and maintaining it in alignment.

Battery alignment is one of the critical factors in the fighting effectiveness of any combat ship equipped with guns or missile launchers. Without proper battery alignment the projectiles and missiles fired will not hit their target when properly aimed—regardless of high crew efficency, high-power radar and optical equipment, speedy fire control computation, or high rate of fire. Maintenance of accurate battery alignment is a primary responsibility of weapons personnel, beginning when the ship is under construction, continuing so long as it remains in commission—even when the ship is retired to the mothball fleet. Battery alignment is not confined to operations at infrequent intervals. Although some alignment operations are performed as infrequently as once every two years, some operations (such as transmission checks) are done every day.

Taking into account in detail all the phases of battery alignment, beginning with the original construction of the vessel, it is evident that the subject is complex and requires close study even by the nonspecialist. This chapter concentrates on principles rather than procedural details, and on alignment afloat, rather than the more complex drydock operations.

7A2. BATTERY ALIGNMENT DEFINITIONS AND DISTINCTIONS

The purpose of battery alignment is to adjust the guns of the battery and associated fire control equipment so that the lines of sight of the director telescopes and gun sights, the beam axes of the radar antennas, the lines of sight of optical rangefinders, and the bore axes of the guns in the battery, are all parallel when

1. dials are matched with correct follow-the-pointer indications,
2. no parallax corrections are introduced, and
3. no ballistic corrections are introduced.

In a correctly aligned system, all associated gun bores, etc. remain parallel under these conditions throughout all operating motions, and all instrument dials and automatic control equipment measure these motions correctly with respect to the proper reference.

To accomplish this, all these elements must be aligned to a common system of reference points, lines, and planes. Battery alignment can therefore be defined as the process of adjusting all the elements of a weapon system (in a gun battery this includes the director, sights, radars, computer and stable element if any, and the gun mount sights and gun barrels) to these common reference points, lines, and planes, and maintaining them in this relationship.

Note these distinctions:

INTERNAL ALIGNMENT refers to adjustment of the geometrical relationships within an element of the fire control or weapon system, such as a mount's gun bore axis and the mount's gunsight mechanism.

SYSTEM ALIGNMENT refers to the geometrical relationships between two or more major components of a system, for example the bore and sight telescope axis of a gun mount as related to the line of sight of director telescopes.

ORIGINAL ALIGNMENT is the initial alignment made in a fire control and weapons system at the time of original construction and installation. This is a very elaborate and highly accurate series of operations done in drydock by the shipbuilder or fitting-out yard. Original

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alignment is also performed whenever a new or modified major weapon system is installed (also usually a drydock operation).

DRYDOCK ALIGNMENT OR REALIGNMENT refers to the thorough alignment overhaul and readjustment made when a ship goes through its regular drydock overhaul period, at intervals usually of two years or longer.

ALIGNMENT AFLOAT refers to alignment operations performed while the ship is waterborne (in port or underway.) These operations are performed much more frequently than the relatively elaborate drydock alignment work. Alignment afloat requires standards of accuracy just as high as those of original alignment. The main difference is that alignment afloat must be performed by weapons department personnel with equipment available on the ship.

TRAIN ALIGNMENT refers to adjusting fire control and weapon system elements so that they are in effect all parallel and are all at exactly the same angle to a selected vertical plane.

ELEVATION ALIGNMENT refers to adjusting these elements so that they are parallel and are all at exactly the same angle to a selected horizontal plane. In both cases, alignment as defined assumes that no ballistic corrections or parallax corrections have been introduced. Train alignment is commonly performed separately from, and before, elevation alignment.

B. Internal Alignment

7B1. INTERNAL ALIGNMENT OPERATIONS

The internal alignment operations that are normally considered within the scope and responsibility of a weapons department aboard ship include

1. gunsight alignment (which includes boresighting),
2. tramming,
3. bench mark checking,
4. director sight alignment, and
5. synchro zeroing.

The first two of these are performed on gun mounts and turrets; Nos. 3 and 4 are performed on fire control directors; and the last is done with nearly all synchros. No internal alignment (within the meaning defined earlier in this chapter) is performed in fire control computers or stable elements.

The five types of alignment operation listed above are not the only internal alignment operations that may be required; they are simply the types of alignment operations that can normally be performed afloat by the ship's force. There are other internal alignment operations that may be required in drydock or during ship construction or major alteration. These include alignment of gun trunnions, shimming of director, mount, or turret roller paths to eliminate warping, installation of bench marks and trams, and the like. All of these require either lifting of major armament units like turrets or mounts, or extensive resurveying of the fire control installation's geometry using special procedures and such equipment not normally aboard combat ships as theodolites and transits. Such operations as these are not described in this book. For such details, see OP 762, Alignment of Ordnance Installations Aboard Ship.

7B2. ERRORS AND THEIR SOURCES

In all internal alignment operations, errors and discrepancies can be traced back to three sources:

1. Human error (observation error).
2. Instrument error (mechanical error).
3. Lost motion.

The first of these is caused by such factors as failure or inability of operating or maintenance personnel to match index marks or graduations, tendency to misread or to read with limited accuracy scale indications, failure to line target points up exactly with reticle crosshair intersections, and the like. This is not necessarily caused by personnel incompetence, though incompetence or carelessness may increase this source of error to serious proportions. The fact is that even the sharpest eyed, most skillful and most conscientious human being has his limitations. To keep adjustments and obserservations as free of human error as possible in

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the usual conditions aboard ship, working personnel take the following measures:

1. Each observation or measurement is made as carefully as possible. This requires that the operation itself be carefully prepared and performed. It is important also to use care in reading dials—to count the graduations accurately, and to look at the dial squarely to avoid apparent displacement (parallax effect) of the index or pointer and the graduations.

2. Critical measurements are taken two or more times, and the recorded value taken is the mean (average) of these.

3. Especially critical observations may be taken not only more than once, but by a different individual each time.

Human error may be consistently in one direction and variable in amount, or (as is rather more common) consistent neither in direction nor amount.

Instrument error (often called mechanical error) is caused by some kind of incorrect setting or relationship in the equipment. It may be caused by incorrect adjustment of a part, or wear, or weakening of a spring, or warping of a shaft, or any number of other causes. Such errors may also be caused (in electrical or electronic equipment) by failure or weakening of a tube or capacitor, or other electrical malfunction. As distinguished from lost motion (see below), instrument error is generally consistent in direction and magnitude. When combined with the effects of human error and lost motion, this characteristic may be obscured.

Lost motion is normally caused by wear and deterioration through either use or lack of use. The term applies to looseness or slackness of linkages of all kinds, whether caused by faulty or sloppy engagement of gears, excess end play of shafting, weakening or failure of springs, or other causes. A mechanism may, because of wear or other causes, bind or stick in some ranges of its operation while it has lost motion in others. A minimal amount of lost motion, like a minimal amount of human error, is in most mechanisms impossible to avoid (though spring loading can in some applications reduce it to zero), and designers provide for such minima by necessity. But lost motion must be taken up by resetting of parts, and replacement of worn parts, as required during repair work.

In certain operations, maintenance personnel can virtually eliminate the effect of lost motion (but not lost motion itself) by approaching each critical observation or reading from a given direction. When doing this, if you overshoot, begin again and approach the desired value from the same direction. But if you are measuring lost motion or actual instrument error itself, you approach first from one direction and then the other, taking a series of readings and averaging to ascertain the values you seek. See the section on alignment afloat for an example of this technique.

Note that these three main types of error don't register separately; they are all nearly always present in some degree. The observations and readings you get include the effects of all three. The effects may either be additive, increasing the net error, or subtractive, partially canceling out and reducing the net error.

7B3. GUNSIGHT ALIGNMENT

Gunsight alignment is that part of battery alignment which involves the mechanical alignment of the parts making up each element, namely, alignment within each mount, turret, or gun of the battery. Gunsight alignment is usually the initial step in battery alignment, and consists of three procedures:

1. BORESIGHTING. The pointer's and trainer's telescopes do not lie on the axis of the bore. For firing at short ranges in local control they must, therefore, be aligned so that their sighting axes intersect the extension of the bore axis at the target. Since, however, the gun bore is only a few feet from the sights, the error which may be caused by parallel alignment is very small. Thus, gun sights may be aligned either to mean battle range for the battery involved or along parallel lines (converging at infinity).

2. CHECKING FOR LOST MOTION. The values of sight angle and sight deflection as set on the sights must not contain inaccuracies due to lost motion in the sight mechanism.

3. CHECKING FOR PARALLELISM OF SIGHTS. Sight angle or range settings must elevate or depress the sighting axis of the telescopes in a plane perpendicular to the trunnion axes, and deflection settings must move the sighting axes of the telescopes in a plane parallel to the trunnion axes; in other words, the sights must be aligned for parallelism. This is not normally performed during alignment operations while afloat.

7B4. BORESIGHTING

The object of boresighting is to make the sight axes and the bore axis converge at either: (1) a specified range, or (2) infinity, with the

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range scale and the deflection scale reading their zero value in either case.

In order to adjust the sights in this manner, use must be made of a boresight telescope. This is a telescope which may be mounted in the bore of a gun and adjusted so that its line of sight coincides with the axis of the bore. Then by sighting through this telescope and through the sight telescopes simultaneously, the latter may be adjusted to obtain convergence or parallelism.

There are two main types of boresights: the breech-bar boresight and the boresight with self-contained optics.

A breech-bar boresight consists of (1) a boresight telescope, (2) an adapter for installing the telescope in the gun, and (3) a muzzle disc used for aligning the telescope on the axis of the bore. With bag-type guns, the adapter takes the form of a breech bar that can be installed across the screw box. A breech-bar boresight can also be used for boresighting a 5"/38 gun, but with a different type of adapter. The same boresight telescope can be used in boresighting guns 5 to 8 inches in caliber (except the dual purpose 6"/47 and the rapid-fire 8"/55), if provided with the proper adapters and muzzle discs.

Boresights with self-contained optics vary in construction and even in principle of operation, from those that consist merely of a fitting with a small hole for the breech end and another with a pair of crosshairs at the muzzle end, to those that convert the gun into a huge (but low-power) telescope. Self-contained optics boresights are made to fit only the guns for which they are designed. No parts of them are interchangeable between guns.

The boresighting process with either major type of boresight is substantially similar, except that breech-bar boresight telescopes must first be aligned on the gun bore axis by sighting on the muzzle disc. This step is not necessary when using boresights with self-contained optics. This section describes boresighting with a breech-bar boresight, because it requires this extra operation. Otherwise, once the self-contained optics boresight is installed, the procedure is exactly like that for breech-bar boresights, as described in articles 7B7 through 7B10.

7B5. BORESIGHT APPARATUS (BREECH-BAR TYPE)

The equipment required at the gun to boresight a bag gun includes, as noted in the preceding article, a breech bar, a boresight telescope, and a muzzle disc. The equipment and method of mounting on a gun are shown in figure 7B1.

The breech bar is a precision-machined bar which can be attached to the face of the breech by two screws. There is a hole through the midsection to receive the outer tube of the boresight telescope.

The boresight telescope tube is mounted within an outside adjusting tube which screws into the breech bar and is locked by means of the locking ring. Within the adjusting tube, the telescope is mounted in a spherical bearing which permits the telescope to be adjusted in both the horizontal and the vertical plane by means of four adjusting screws, so that the axis of the telescope can be made to coincide with the axis of the bore. The telescope has three rings near the eyepiece: (1) the reticle focusing ring for focusing the eyepiece to the individual eye, (2) the objective focusing ring for focusing the telescope on the target and eliminating parallax error (apparent target displacement when the eye is shifted about the optical axis of the eyepiece), and (3) the rotating ring, which permits rotation of the telescope about its axis within the outer adjusting tube.

The muzzle disc is a circular casting designed to fit snugly in the muzzle of the gun. Through the center of the disc is a small hole, and around it are four larger holes, arranged as shown in figure 7B1. Etched rings around the edge of the disc provide means for fitting the disc in the muzzle perpendicular to the axis of the bore. Notches are engraved on both disc and gun as index marks. With these index marks matched, one row of holes is aligned vertically and the other horizontally with respect to the gun. The purpose of the disc is merely to assist in the alignment of the boresight telescope axis with the bore axis.

Once aligned, the muzzle disc is removed and has no further part in the boresighting of the gun until the final stage, when it is remounted for a recheck of alignment to assure that no error has crept in during the process. Boresights with self-contained optics do not require the use of a muzzle disc in obtaining alignment with the bore axis.

7B6. BORESIGHTING PREPARATION

The general steps necessary in getting the gun ready for boresighting are as follows:

1. See that the pointer's and trainer's scopes are clear, focused, and free from parallax.

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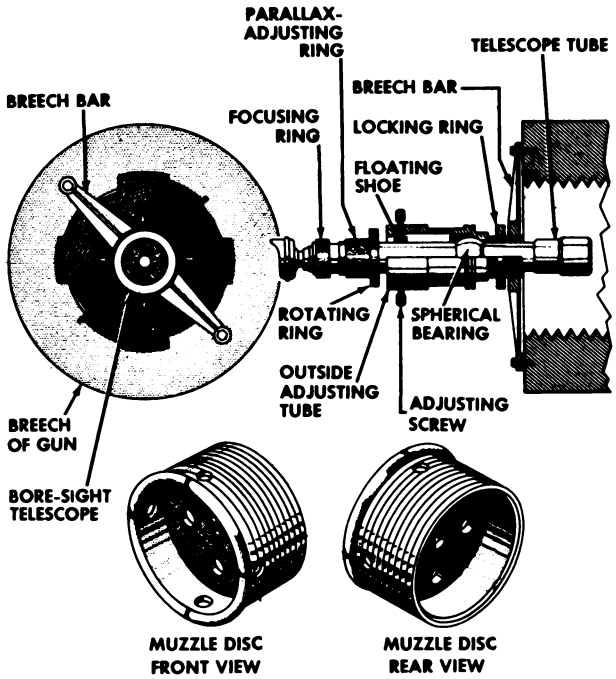

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Figure 7B1.—Boresight apparatus.

2. Remove all evident lost motion from the sight mechanism. (See article 7B8.)

3. Lash back the breech plug so that motion of the ship will not swing the plug against the boresight apparatus. (For case guns, make sure that the breechblock is securely held down.)

4. Install breech bar, boresight telescope, and muzzle disc. (For boresights with self-contained optics, only the boresight components are installed. No muzzle disc or breech bar is required. Steps 5 and 6 below are also unnecessary as is the final step in article 7B9.)

5. Focus the boresight telescope and center the crosshairs on the small center hole in the muzzle disc, using the four outer holes to align the crosshairs vertically and horizontally.

6. Remove the muzzle disc.

7. Set the range scale at zero (sight angle scale set at its zero value—usually 2,000 min) and deflection scale at the midpoint (usually 500 mils).

7B7. CHOOSING A TARGET

A target with a clearly defined and visible point is suitable for boresighting in both deflection (train) and elevation. In the absence of such a target, two targets may be used: one with a clear vertical line of boresighting in deflection, and one with a clear horizontal line for boresighting in elevation.

If the guns are being readied for a specific gunnery practice, the target selected should be at the range specified for that practice. For general use a target should be chosen at about the range at which the guns being boresighted are most effective, called the mean battle range. Or, if a parallel alignment is desired, a distant target like the moon or a star may be chosen. When the moon is used it is called "shooting the moon." For elevation only, the horizon often makes an excellent target, especially for such guns as the 5-inch and 6-inch, for which it roughly corresponds to mean battle range.

7B8. LOOSENESS OF PARTS AND LOST MOTION

Before beginning the actual boresighting, check for looseness of parts and for lost motion in the gunsight mechanism.

To check for looseness of parts, first sight on some convenient target. Then manually shake all adjustable parts, and recheck the crosshairs on the target. If the sights are off, tighten the kinkage and try again. This check should be performed independently for the trainer's and pointer's telescopes.

To check the sight mechanism for lost motion, set the sights so that the crosshairs are on a target whose position with respect to the gun remains fixed. Use a point on the ship itself or, if the ship is in drydock, a target outside the ship. While this check is going on, keep the gun stationary.

Set the sights at maximum range on the range scale and then return them to their original setting. If there is no lost motion, the horizontal crosshair will return to its exact position on the target. Make a similar check for the vertical crosshair by setting maximum sight deflection, returning to original deflection setting, and observing change due to lost motion, if any.

If there is lost motion in the sight mechanism, it can be removed by taking up excessive play or clearance between moving parts.

7B9. BORESIGHTING THE GUN

To boresight in train, bring the gun to bear on the target so that the vertical crosshair of the boresight telescope is aligned with a vertical

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mark on the target. As the ship pitches and rolls, at the instant when the boresight is on, the man at the boresight calls "Mark." If the pointer's and trainer's vertical crosshairs are not on target at this instant, adjust the sight deflection input coupling to the telescopes until all vertical crosshairs are on at "Mark." Similarly, to boresight in elevation, align the horizontal crosshair of the boresight telescope with a horizontal mark on the target. Adjust the sight angle input coupling to the telescope until all telescopes are on with the boresight telescope.

The sight checker's telescope should also be adjusted in both deflection and elevation.

After boresighting, recheck for looseness of parts. Before securing, place the muzzle disc in the gun to make sure that the boresight line of sight is still coincident with the axis of the bore. If it is not, boresighting must be repeated.

7B10. CHECKING PARALLELISM OF SIGHTS

As mentioned earlier, this is not normally performed as a separate operation except while the ship is at a shipyard, and it will therefore not be detailed here. In one method of performing this check, a flat wooden screen with suitable target markings (called a batten) is secured to the gun chase near the muzzle, and the parallelism of the sights is checked by observing how accurately the sight reticles follow the target markings as the gun is elevated and depressed.

The boresighting procedure for an infinitely distant target, as described above, adjusts the sights for parallelism with each other as well as with the bore axis.

7B11. OTHER BORESIGHTING METHODS

Except for the alignment steps requiring use of the muzzle disc, the boresighting method using self-contained-optics boresights resembles the method described above. Boresighting at battle range rather than infinity is common for smaller gun mounts; this requires either selection of a target at suitable range or the use of marked batten boards mounted on the deck. The batten board method is used relatively rarely and will not be described here.

7B12. TRAMMING

When you measure gun elevation and train, you specify the angle between the axis of the gun bore and a plane parallel to the selected horizontal reference plane (for elevation angle), or between the axis of the bore and a plane through the centerline of the ship and perpendicular to the selected horizontal plane (for train angle).

When a gun mount or turret is installed, its train angle and elevation angle are very carefully measured at selected gun mount positions. The selected positions for train and elevation are accurately designated by metal markers or tram blocks welded to the structure of the gun mount. These selected angles of elevation and train are recorded in the battery or mount log, and remain on record so long as that ordnance installation remains on the ship. Tramming is the procedure for verifying that when the mount or turret is positioned at the selected angles, the train and elevation indicators display the values prescribed. There is but one elevation angle and one train angle at which any individual mount or turret can be trammed.

Tram blocks are steel blocks welded to the mount structure in pairs, one pair for elevation, one for train. Figure 7B2 illustrates 5"/38 tram block arrangement for a single mount. One of the pair of blocks for elevation is secured to the mount carriage (which does not move in elevation); the other of the pair is secured to the slide (which does). Similarly, one of the pair for train is welded to the mount base ring,

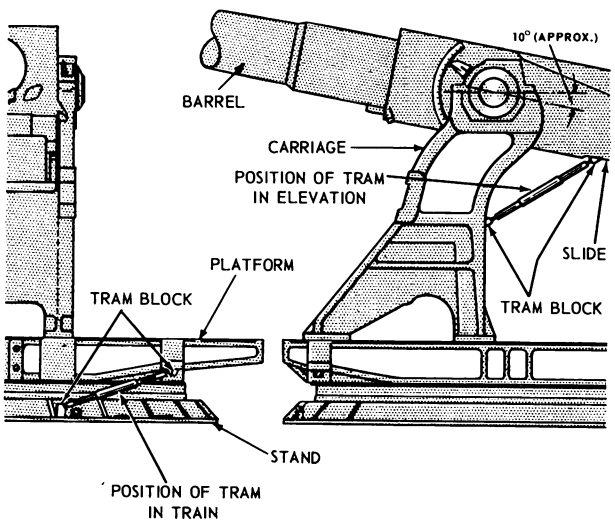

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Figure 7B2.—Tramming a 5"/38 single mount in elevation and train.

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which moves in train; the other is welded to the stand, which is secured to the deck. Tramming in train is one operation and tramming in elevation another. These operations are performed successively. Only one tram is used at a time, not two at once.

A typical tram block for a 5"/38 mount is shown in cross section in figure 7B3. Imbedded in the block is a short steel rod whose outer end is cupped to take the tram. The tram block face is covered with a metal cap and packed with grease to prevent corrosion. The block is uncovered only for tramming, and is repacked when the cover is replaced.

The tram itself has two rounded ends. One is part of the body or barrel, and the other is part of the spring-loaded plunger that can move within the barrel. Across a small window in the barrel is an index line. A line on the sleeve is matched up with the barrel index line by moving the sleeve in the barrel.

Here are the main steps for tramming in train:

1. Set the mount parallax indicator (if any) at zero. Train the gun until the train-angle indicator shows that the mount is at the approximate train angle for tramming. The value of the angle is entered in the battery log.

2. Uncover the tram blocks for tramming in train, and seat the ends of the tram firmly in the rods of the blocks. Train the mount if necessary to do this.

3. With the tram ends seated, train the mount carefully in manual to compress the tram until the marks on barrel and plunger line up exactly.

4. Take a reading on the train-angle indicator dial. It should agree exactly with the value given in step 1 above. If not, the indicator should be adjusted until it does.

The tramming operation in elevation is similar to that for train, except that the mount must first be trained to a point at which roller path compensation is zero. (This is 90° from the roller path high point.) This train angle is recorded in the fire control log, or can be read on the roller path compensator dial. Use the elevation tram blocks and elevation angle dial. The same tram is used in elevation and train.

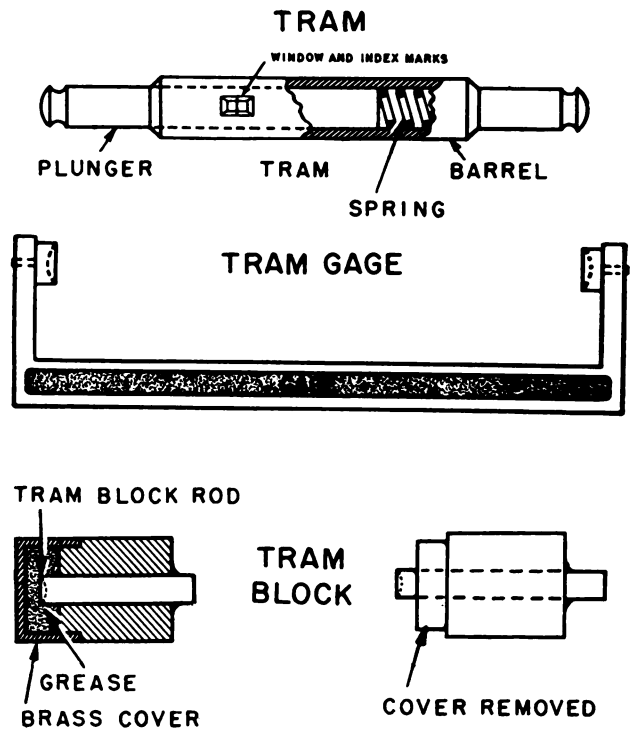

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Figure 7B3.—Tram, tram gage, and tram block.

7B13. BENCH MARK CHECKING

Director sight alignment is in principle analogous to gun mount boresighting and sight alignment, and bench mark checking of a director is equivalent to gun mount tramming. It is important that the director be bench mark checked before any guns are aligned with it. A bench mark is an engraved metal plate secured to a fixed point on the ship's structure (e.g., the deck or a fixed bulkhead on the superstructure). When the director is cranked to a prescribed position in elevation and train, the director pointer looking through his telescope should see the reticle's crosshairs coincide with the bench mark's engraved target diagram. This is the principle of the use of the bench mark. In practice, the basic procedure is approximately as follows:

1. If the director uses parallax corrections, set these at zero.

2. If the director uses inputs of level and crosslevel, set these at zero.

3. Obtain the bench mark reading from the ship's records.

4. Move the director until the crosshairs of the pointer's telescope are on the bench mark.

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5. The train and elevation dials should now read the previously recorded bench mark values. If they do not, the dials must be adjusted until they do agree with the bench mark values, with the crosshairs still on the bench mark.

Because of flexing of the ship's structure while afloat, small periodic errors may develop which cause corresponding discrepancies in bench mark observations. So long as they do not increase systematically in one direction, and so long as they remain small (on the order of 2 to 3 minutes), the weapons officer may choose to ignore them. Whenever a ship is bumped while mooring or weathers a bad storm at sea, it is a good idea to check bench mark values at the first opportunity.

7B14. DIRECTOR OPTICS AND RADAR ANTENNA ALIGNMENT

Present types of gun fire control directors range from small lead-computing types with but one lead-computing sight and no radar to directors with two telescopes, slewing or battery officer's sight, stereoscopic rangefinder, and radar antenna. The details of sight alignment procedures vary from one mark and mod to another, but the principles for all of them are similar, and resemble those brought out in connection with gun mount boresighting. As they apply to fire control directors, these principles can be summarized as follows:

1. One line of sight (in the Mk 37 director, for example, that of the pointer's telescope) is used as a reference for train, elevation, or both. All other lines (in Mk 37 the train telescope line of sight, the rangefinder line of sight, the slewing sight line of sight, and the radar antenna axis) are adjusted to it. The reference line has originally been adjusted on the director bench mark. (See the previous article.)

2. All ballistic corrections are reduced to zero, parallax correction is set at zero, and level and crosslevel are locked at zero.

3. A suitable target is selected at a minimum range of several thousand yards (the exact value is prescribed in the applicable type commander's instructions), and the director is trained and elevated until the reference line of sight is aligned with the target. The other lines are then adjusted so that all are on the same target. An astronomical body is suitable for this operation so far as optical lines of sight are concerned, but not for radar.

4. The radar antenna axis is aligned with the other lines on a distant visible nonastronomical target (helicopter or radar reflector mounted on a motor whale boat) that gives a clear response on the radar tube and provides optically and on radar a good point for alignment. The procedure is first to put the director precisely on target optically, and then to adjust antenna alignment to give optimum "on target" indication in the radarscopes.

5. Dials and synchro transmitters may be aligned at a suitable point in the procedure. All dials should agree with the dial on the reference line of sight instrument (e.g., in Mk 37 directors this would be the pointer's dial). All synchros should be zeroed to the corresponding dials, in a separate operation.

7B15. SYNCHRO ZEROING

Most fire control directors transmit their outputs to other units in the system by means of a-c synchro transmission. The synchro-zeroing phase of internal alignment is designed to ensure that when a given dial or pair of dials read zero, the corresponding synchro transmitters are producing the zero-position voltage pattern. The procedure for verifying the transmitter zero position is to let its output drive a synchro receiver to approximate zero position, then use a sensitive a-c voltmeter to make the fine adjustment: Where synchro transmitters are paired in double speed, each synchro must be zero-checked separately. Because bias voltages from sources outside the synchros are used in some double-speed systems, the zero-checking should be done directly from the synchro terminals, not from terminal boards or other points in the circuit.

Other types of synchros are zeroed by using modifications of this fundamental procedure. For details of all synchro zeroing and other adjustment operations, see OP 1303.

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C. Alignment in Drydock

7C1. INTRODUCTION

So far as battery alignment is concerned, the Weapons officer is concerned principally with alignment afloat, rather than with alignment in drydock, which ordinarily occurs only at intervals of two years or more. For this reason, the description of drydock battery alignment operations is presented briefly and without full details. For details, see OP 762, and Weapons detailed instructions issued by the Bureau of Naval Weapons and Type Commanders.

7C2. ORIGINAL ALIGNMENT IN DRYDOCK

The original alignment of ordnance installations is made in drydock. Battery realignment in drydock usually takes place during regular overhaul periods thereafter.

Its two principal phases are alignment in train and alignment in elevation. In the following discussion it is assumed that all elements of the system already have been properly installed and are functioning properly, and that these elements are mechanically aligned within themselves.

7C3. ALIGNMENT IN TRAIN

The purpose of battery alignment in train is to adjust the battery so that when the dials are matched, and no ballistics or horizontal parallax are introduced, the lines of sight of directors and guns, and the axes of the bores of the guns, are all parallel in train at any angle of train.

The first step in actual alignment in train is to establish a centerline from which to measure horizontal angles. In most cases, because of the interference of the ship's structure, this line will take the form of an "off-set centerline" ashore, parallel to the real centerline of the ship. The centerline is established by use of surveyor's transits.

Next step is to establish the center of rotation of each trainable element (such as gun mounts and directors), so that a transit may be set up to measure the true angle of train of the element. After it has been plotted, the center of rotation must be checked when the element is trained. When verified, the center of rotation is permanently engraved so that it can be used in future checks. On enclosed mounts, the mark is on top of the shield.

It is now necessary to establish zero train—that is, to set the train dials of each element so that when the dials read zero train, the line of sight or bore axis of each element is parallel to the centerline of the ship, and pointing forward. On the after elements the dials are set at 180°, with elements pointing aft and parallel to the centerline.

With zero train established and the dials set, permanent reference marks must be established. A bench mark and angular reading for each director and a tram reading for each mount or turret are established. At any future time when it is necessary to verify dial accuracy, each element can be trained onto its reference and the dial readings checked, as described in earlier articles in this chapter.

7C4. ALIGNMENT IN ELEVATION

After battery alignment in train comes alignment in elevation. The purpose of alignment in elevation is to adjust the battery so that at any angle of train, and at any angle of elevation, the lines of sight of directors, the lines of sight of gunsights, and the axes of the bores of guns, will all be elevated by exactly the same angle above a common reference plane. (Again, we assume no vertical parallax or ballistic correction, and that dials match.)

The reference plane chosen is an actual plane on the ship; that is, it is the plane of the roller path (main horizontal bearing) of one of the elements of the battery. Ideally, the plane chosen must have the smallest possible inclination between it and the roller paths of the other elements of battery. The choice of this plane will vary, depending upon the type of ship. Because AA or dual-purpose battery directors can control more than one battery, one standard reference plane for all batteries is necessary.

Elevation alignment is principally concerned with one primary factor—the tilt or inclination of roller paths. The effect of the roller path tilt or inclination on elevation, if not corrected, is shown, greatly exaggerated, in figure 7C1. Each of the two gun mounts in the figure is elevated to the same angle (A) with respect to its roller path, but the angle of each (B and B') with respect to any common reference is not the same.

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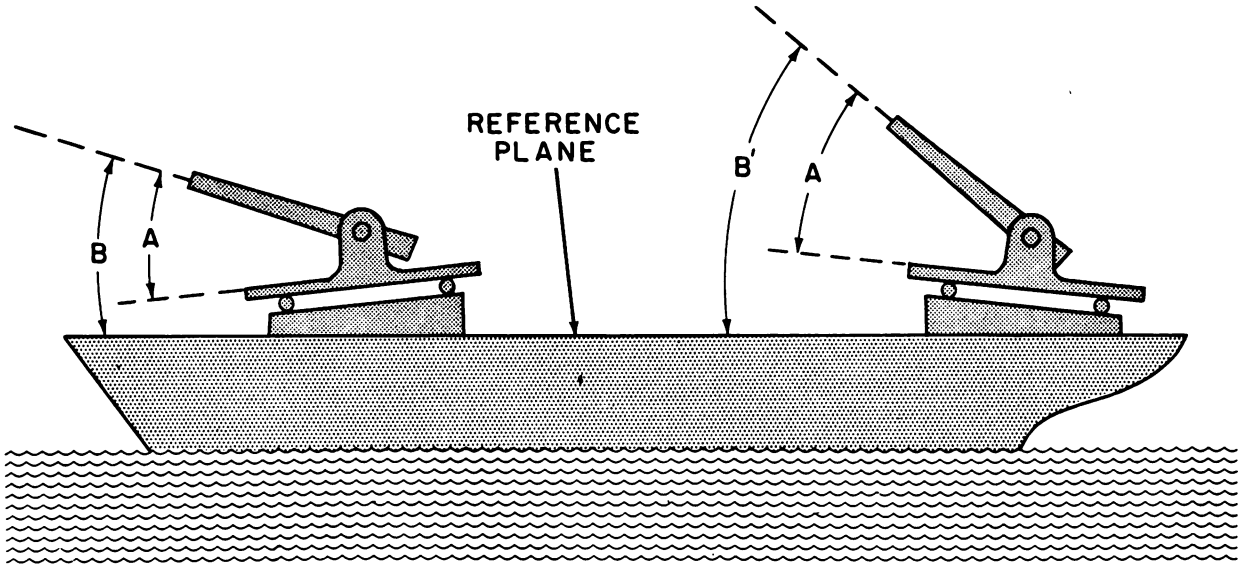

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Figure 7C1.—Effect of roller-path inclination on elevation.

The principal operation in elevation alignment in drydock is the procurement and interpretation of roller path data. Roller path data are actually a series of readings showing the inclination of a trainable element (usually a gun mount or director) at points all around the roller path, relative to some fixed plane. In drydock this is usually a horizontal plane established by a level. The relationship between any roller path and the horizontal is defined by the amount of tilt at the highest point of the path, and the relative bearing of this point. Figure 7C2 shows this diagrammatically.

These data are determined by measuring roller path inclination at regular angular intervals through the full arc of train possible with the mount or director, tabulating them, and plotting them on coordinate paper. The general procedure for plotting and interpretation of the data resembles the afloat system alignment procedure described later in this chapter.

The instrument most commonly used for elevation alignment procedures in drydock is the gunner's quadrant. This instrument, which is illustrated in figure 7C3, is a high-precision device designed to measure the angle of inclination of a flat surface with respect to the true horizontal. (The true horizontal is defined as a plane tangent to the earth's surface at the point of measurement.) Two types are in common use; figure 7C3 illustrates the Mk 3 Mod 1, which is characterized by a vernier scale to give maximum accuracy. The instrument consists of a base, the bottom of which is ground to an accurate plane surface, an arc mounted perpendicularly on the base, an arm containing a spirit level, and a clamp arm. The level and clamp arms are pivoted. The clamp screw can secure the level arm at any desired position on the arc. The clamp arm is connected to the level arm by a tangent screw for making fine adjustments. The level in the level arm is a slightly curved graduated glass tube filled with colored alcohol and containing an air bubble. The level arm also carries the vernier scale, which slides along the arc, and a magnifier glass.

In use, the instrument is placed with its flat base on the surface whose inclination is to be measured (the slide of a gun, for example), with the quandrant pivot toward the center of rotation, and the level and clamp arms are adjusted until the level bubble is centered in its graduations. Small adjustments can be made with the tangent screw, and the inclination is read with great precision from the graduated arc and vernier.

In gun mounts and turrets, compensators correct for roller path tilt by adding a compensating tilt algebraically, depending on mount train

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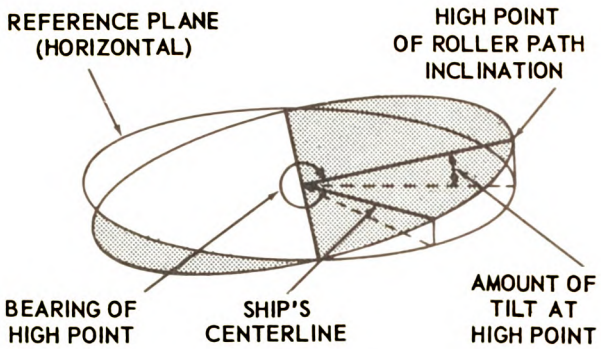

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Figure 7C2.—Relationship between roller path and horizontal.

angle. The amount of the correction is at each point in train equal to the amount of tilt, but opposite in direction. Figure 7C4 shows the dial of a type of roller path compensator used in many 3" mounts. The "B" scale is driven by the training gear and shows the angle (0° is displayed in the figure) between the present position of the mount and the high point on the roller path. The "A" scale index pin, which is set by maintenance personnel, shows the amount of tilt tabulated or plotted for the high point of the roller path. This automatically introduces the proper elevation correction at every train angle. Index "C" shows mount train position (180° is displayed in the figure).

In ships with more than one director, most of the directors are normally equipped with

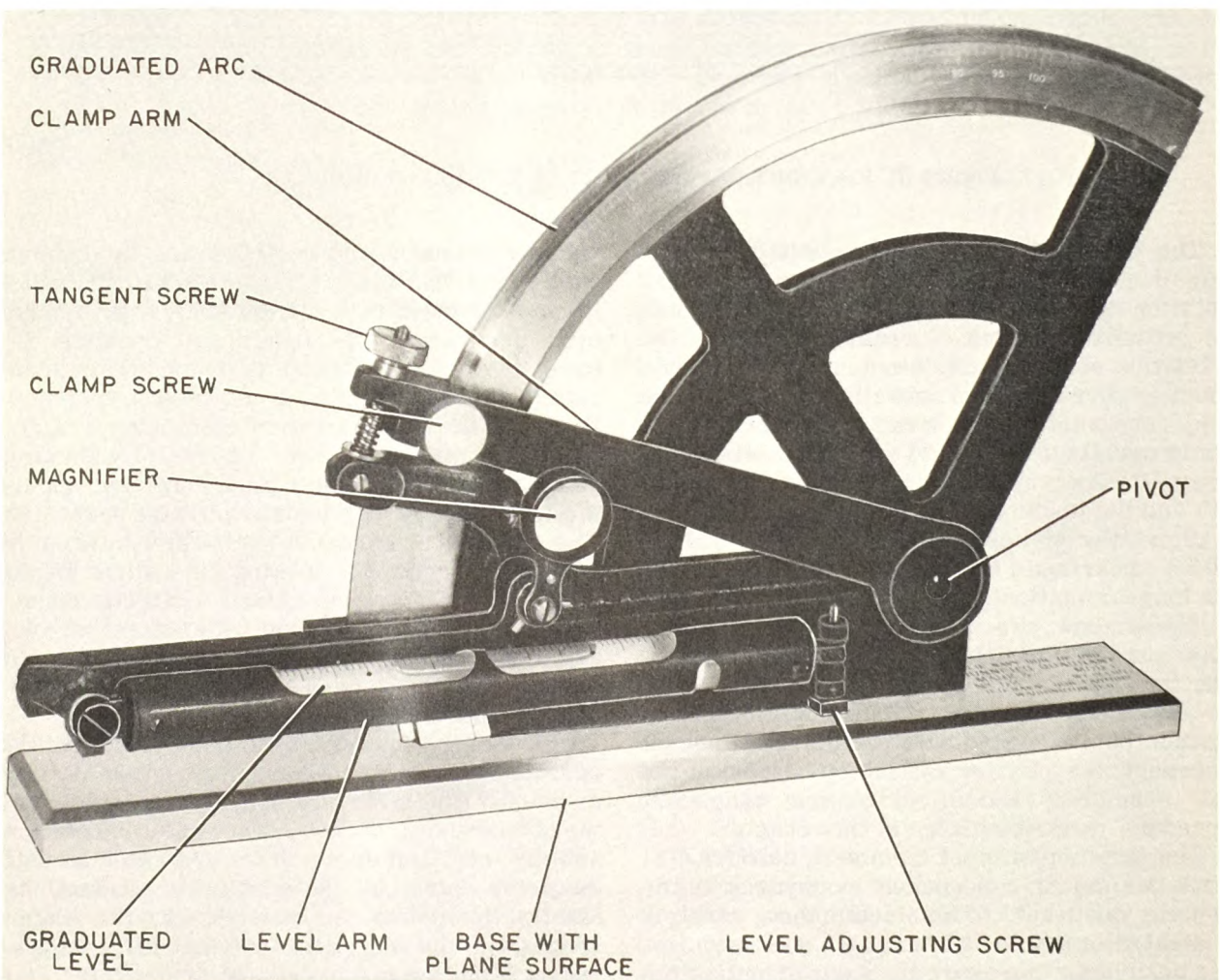

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Figure 7C3.—Gunner's quadrant Mk 3 Mod 1 (vernier scale type).

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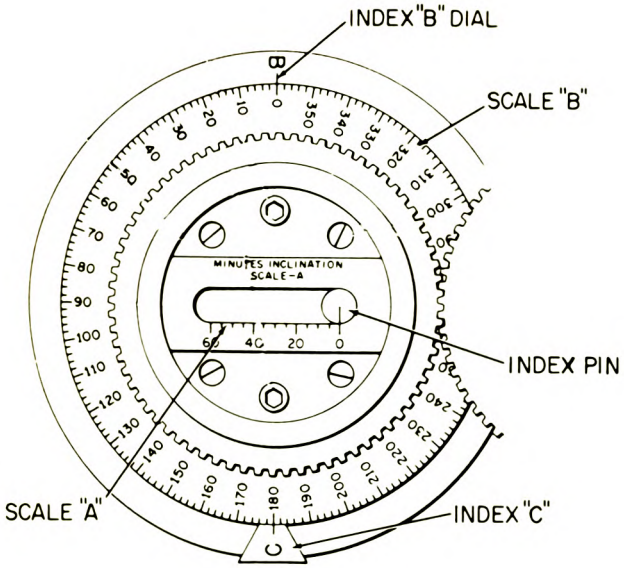

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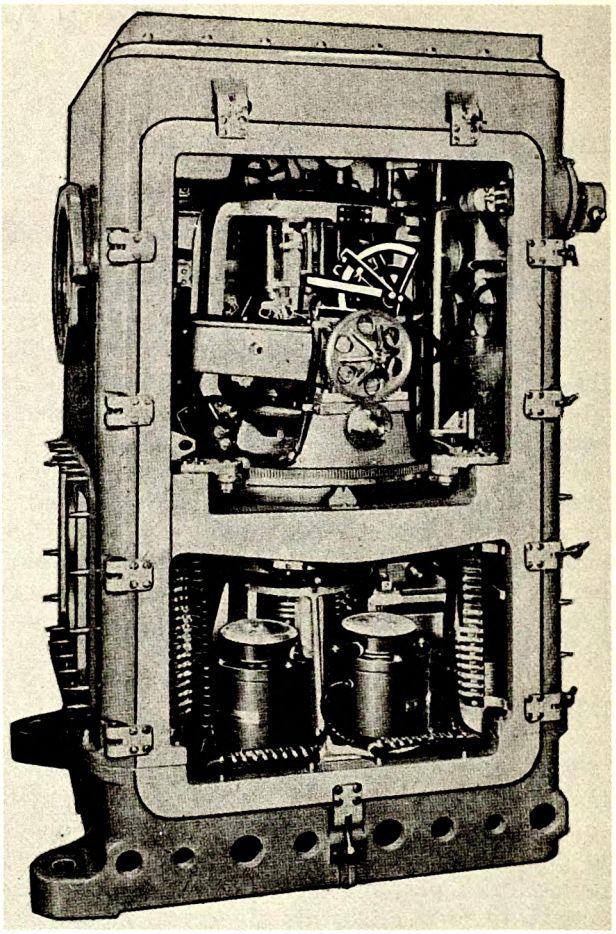
Figure 7C4.—Roller path compensator.



53.128
Figure 7C5.—Gunner's quadrant installed to check alignment of stable element.

roller-path compensators which in principle function as described above.

After the reference plane of the battery has been established, the next step is to align the stable vertical or stable element so that the plane of its roller path is exactly parallel to the reference plane. This is necessary because the stable element measures continuously the tilt of its roller path (which represents the reference plane) with respect to its gyrostabilized parts. Since this correction is applied to gun elevation, the stable element's roller path must be parallel to the reference plane, so that its tilt at any instant will be the same as those of the director and the gun mounts.

No roller path tilt corrector is provided for the stable element. Stable element correction is introduced by shimming the roller path until it is parallel with the selected reference plane.

This is a precision operation which requires (1) measurement of tilt with a gunner's quadrant, (2) tabulation and plotting of the tilt data, (3) calculation of the required thickness of the shims to be inserted under the roller path, (4) fabrication, machining, and installation of the shims, and (5) recheck through the full angle of train with the gunner's quadrant. Figure 7C5 shows a stable element with gunner's quadrant installed to check alignment.

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D. Battery Alignment Afloat

7D1. REQUIREMENT FOR BATTERY ALIGNMENT AFLOAT

Since a ship is not a rigid structure, upon loading and putting to sea the space relationships between elements of a battery change, and correction for these changes must be made. The process involved is known as battery alignment afloat, and must be carried out while the ship is waterborne, by different procedures than those used for the original alignment in drydock.

Before initiating the actual alignment procedures, ensure that all elements are functioning correctly and that all transmission systems are properly adjusted. Have a routine transmission check carried out just prior to the alignment check. (For more detailed procedures see OP 2456, Volumes 1 through 8.)

7D2. TRANSMISSION CHECK

Before proceeding with the alignment it is desirable to check the synchro transmission system to assure (1) that the transmitters are sending out a correct electrical signal for a given mechanical input, and (2) that the receivers are accurately converting this electrical signal into a mechanical or electrical signal equal to that of the transmitters. It is first necessary to set the synchros to electrical zero. Any of several methods may be used, and each synchro dial should read zero when that synchro is on electrical zero. The next step is to check transmission, which is accomplished as follows:

1. Man the telephones at the stations to be tested.
2. Set the fire control switchboard in turn to transmit from:
   a. The directors to plot.
   b. Plot to the gun mounts.
   c. The directors to the guns directly (bypassing the rangekeeper or computer, where possible).
   d. The stable element to the directors (to transmit level and crosslevel).
3. Turn each transmitter to various readings, usually in 10° increments throughout its operating range, and compare the received readings with the transmitted values. They should check exactly. Any errors of position, direction, or firmness of position should be investigated by standard synchro methods. Particular attention should be paid to the action of the receiver dials when coming to rest. They should stop quickly and evenly in agreement, and there should be neither sluggishness nor long oscillation.

7D3. GENERAL PROCEDURE

Train Alignment. The purpose of afloat battery alignment in train is to ensure that when the director is trained to any point and the gun dial pointers are matched, with zero settings of sight deflection and parallax, the director and gun lines of sight and the gun bore axes are parallel (in the horizontal plane).

Since it is impracticable to use multiple targets, train alignment is checked on a single target with parallax correction. When the gun dial pointers are matched, proper parallax set in, and zero settings of sight angle and sight deflection set in at the guns, the director and gun lines of sight and the gun bore axes, will, if the system is properly aligned, converge on any given target at any range and on any bearing.

To accomplish this check, it is necessary to introduce parallax both into director train (in multiple director installations) and into gun train. It is therefore necessary to check the parallax system before beginning the actual alignment. Proper correction of parallax errors is important where there are a number of directors and large horizontal distances between units. Hence, all parallax correctors on guns and directors should be checked for:

1. Correct amount of parallax at various bearings and ranges.
2. Correct direction of applied parallax correction,

Elevation Alignment. The purpose of afloat battery alignment in elevation is identical with the purpose of elevation alignment in drydock. This objective is attained by selecting some plane as the reference plane of the battery, so that the elevation of all units, when measured from that plane or a parallel plane, is equal. Again, a single target, the horizon, is used for the check.

7D4. SYSTEM ALIGNMENT IN TRAIN (TRAIN CHECK AFLOAT)

After the director is on the bench mark, it is possible to proceed with actual alignment of the

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various battery elements. Preferably, this should be done with the ship at anchor in smooth water. If the battery has never been aligned, a complete train check must be made, but otherwise a preliminary test may be made to determine if a complete check is necessary. The preliminary test is conducted as follows:

1. Establish telephone communication between director and guns.
2. Set switchboard for normal operation; i.e., director to plotting room, which in turn transmits to guns.
3. At the computer or rangekeeper, have time motor off, power switch on.
4. Set Vs (sight angle) on 2,000 minutes and Ds (sight deflection) on 500 mils (their zero values) on their respective computer counters.
5. Set and lock level and crosslevel at zero.
6. At the guns, set zero values of Vs and Ds; put the guns in local, hand, or manual control.
7. Select a distant target off one beam. Train the director until the vertical wire is just off the target, so that motion of the ship will carry the wire across the target.
8. Obtain the range to the target by the most accurate means available, and set the parallax correctors to give the proper correction for this range.
9. Match pointers at the guns.
10. As the director line of sight swings on target, the director trainer calls (phone) "Mark" to the gun trainer. This is continued, the gun trainer meanwhile moving the gun, from one direction, until both gun and director telescopes are on the target at the same instant. The amount of displacement between the follow-the-pointer dials at the gun is the amount of error and should be recorded. This process is repeated, with the gun trainer bringing his vertical wire on target from the opposite direction, and the error recorded. The algebraic difference between the two errors is the lost motion of the gun. The mean of the two errors is the gun error. The example below illustrates how this is done. Assume that the process is repeated three times. The gun trainer notes the following readings on the call "Mark" as he trains his gun onto the target alternately from left and right; the director calls "Mark" on target at his train dial reading of 011°00' each time.

The total absolute difference (regardless of sign) in the three sets of readings (total of column (5) figures) is 12; dividing this by the number of observations (3) yields the mean lost motion: 4 minutes. Columns (2) and (4) show the difference in each reading between the director's train dial indication and the gun mounts train dial indication at the instant of the call "Mark" (when the director train dial read 11°00'). These values bear algebraic signs. The column (2) total is -4; the column (4) total is +8; the algebraic sum is therefore +4. Dividing this by 3 to get the average, we have the value +1.33' (rounded). This is the gun trial dial mean instrument error; it indicates that, disregarding lost motion, the gun train dial tends to read on the

(1) Approaching from the left	(2) Algebraic difference from director	(3) Approaching from the right	(4) Algebraic difference from director	(5) Absolute difference (between colums (1) and (3) regardless of sign)
1. 010°58' - - - - - -	-2	011°02'	+2	4
2. 010°59' - - - - - -	-1	011°03'	+3	4
3. 010°59' - - - - - -	-1	011°03'	+3	4
Total - - - -	-4	- - - - - -	+8	12

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average 1.33 minutes higher than the director train dial, for the same target, and without ballistic or parallax corrections.

The principle described here applies wherever multiple readings are used to determine instrument errors and lost motion.

11. Repeat the process, using a target on the other beam if practicable, and in any case a target at a widely different train angle from the first, and record the gun error and lost motion.

The gun errors should be equal and small. If they are equal and large (2 or 3 minutes larger than the lost motion), it is an indication that a constant error exists, and that this error may be corrected by adjusting the train response. In so doing, the dial which shows the actual train of the element (not the dial on the synchro receiver) must be moved. If the errors are not equal, a complete train check is necessary.

The complete train check is exactly like the test described above, except that a series of targets is used, at 10° or 15° intervals if possible.

The complete train check will furnish gun errors which, when plotted with their bearings as abscissas, should show a slightly ragged scattering of points. A line parallel to the abscissa which passes through the mean of these points (i.e., with approximately equal deviations above and below the line) can be considered as the zero error line. Its distance above the abscissa will be the constant error of the system, which can be removed by adjusting the response. If a sine curve results, it indicates errors such as improper parallax settings. If the points are erratic with large deviations from the zero line, it indicates damage to the dial drive shaft, such as a sheared coupling or slipping gears.

7D5. SYSTEM ALIGNMENT IN ELEVATION (HORIZON CHECK)

To adjust the battery to its reference plane, it is necessary to compile data on the relative positions of all guns with respect to the reference plane as represented by the line of sight of the reference director. This is done by means of a horizon check, which compares the elevation angles on the dials of director and guns when all are laid successively on a series of points completely around the horizon. If we compare director elevation and gun elevation at a common point (horizon), after accounting for any known angular divergences between the two units, such as that caused by the vertical distance between guns and director and the angle of the gun sights with respect to the bore axis (sight angle), their elevations should be equal.

Figure 7D1 shows the essential geometry of this operation. For the moment assume that there is no uncorrected inclination of the gun mount roller path, and that the reference plane is horizontal. The line of sight from the director telescope (which is a little more than 100 ft above the ship's waterline) to the horizon is AB; the line of sight from the gunsight telescope (about 17 ft above the waterline) is CB. Both lines of sight are depressed below the horizontal; the higher you are above the water, the greater the depression angle or dip will be. (Bowditch's American Practical Navigator has a table of dip values and range to the horizon for many values of height above the water surface.) Figure 7D1 shows a dip of -10' for line of sight AB and a dip of -4' for CB. The dip difference is -6'.

To simplify mechanics of tabulation and calculation, the gun is customarily elevated by an arbitrary elevation angle (E'g) in performing the horizon check (in this case, 20'). (See the appendix for a table of fire control symbols.) However, since the gunsight telescope is depressed 4' below the horizontal because it is pointed at the horizon, the value of sight angle (Vs) is actually 24' (the sum of E'g and gunsight LOS dip.)

On the gun mount dials, zero gun elevation (gun parallel to reference plane) is arbitarily called, as you already know, 2,000'. The director line of sight (LOS) is dipped -10' when pointed at the horizon. If roller path tilt is correctly compensated in the gun mount (and in the director if the director has a compensator), then, after applying an algebraic correction equal to the sum of dip difference and arbitrary Vs, gun elevation should equal director elevation. (The gun elevation value corresponding to -10' director elevation is, of course, 1,990'.)

In figure 7D1, if we subtract Vs and dip difference from gun elevation, we arrive at line CD of the diagram (see numerical example as well). If CD is parallel to AB, the gun and director are elevated at equal angles above (below) the reference plane, are aligned in elevation, and there is no system error. Or;

$$E'g - (Vs + \text{dip diff.}) = Eb$$

Now, by rearranging these quantities slightly, to:

$$Vs + \text{dip diff.} = Eb - E'g$$

we can obtain an array of values that provides for checking with minimum time and effort.

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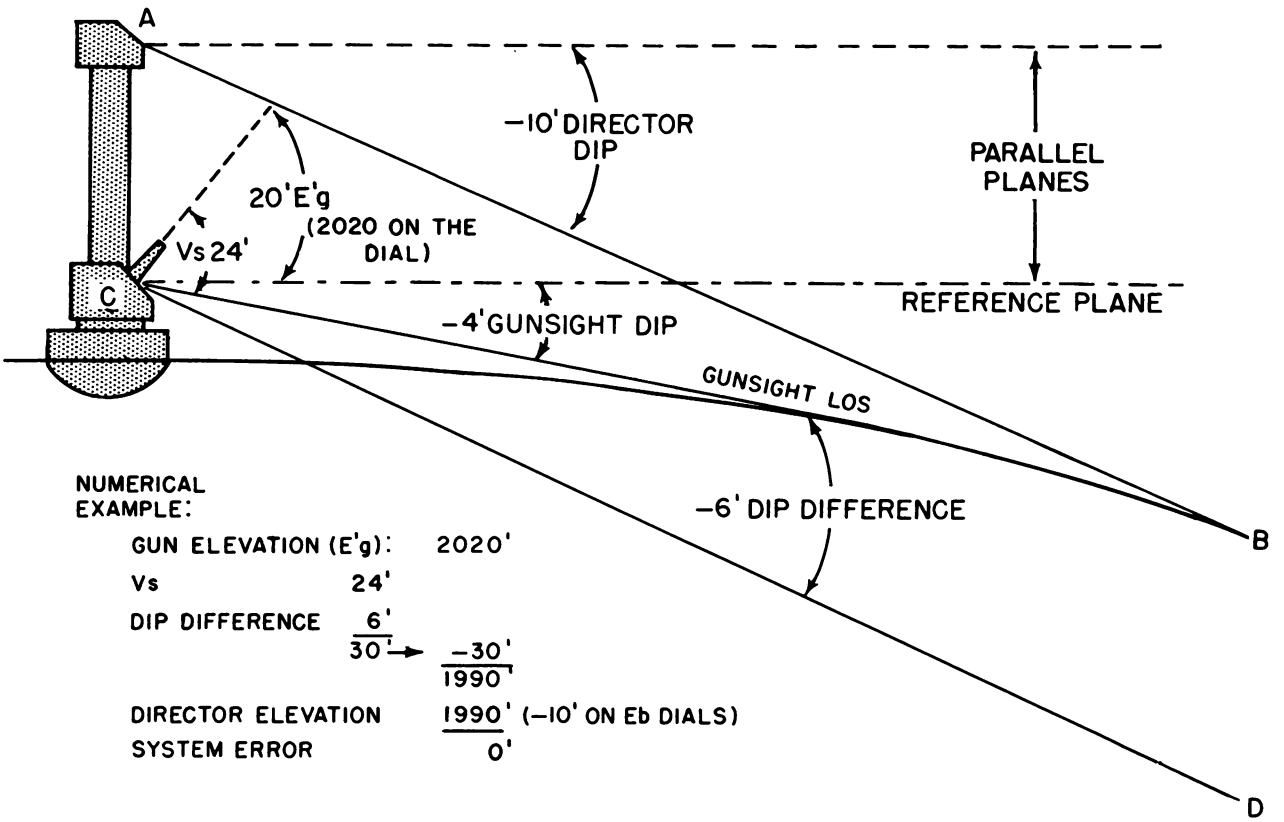

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Figure 7D1.—Horizon check for alignment in elevation using mount gun sight. NOTE: Numerical values given to angles are for purposes of illustration. Assume horizontal and reference planes coincide.

We simply subtract gun elevation from director elevation (values read at each different angle of train) and the result should equal Vs+dip difference (values that are set and remain constant throughout the check).

Steps in performing a horizon check are as follows:

1. Choose a day when the ship has little roll and the horizon is clearly defined.
2. Man stations and phones.
3. Make sure that the synchro transmission system has been checked recently, and that the director has been checked on its bench mark.
4. If possible, use the reference director with no roller-path inclination compensator.
5. Record the roller-path inclination compensator setting on the gun concerned. It should agree with the value determined during the last system alignment check in elevation.
6. Look up the height of gun and director, and compute the dip to the horizon from each. From this information can be computed the dip correction for each gun, by subtracting the dip angle for the gun from that for the director.
7. Set the dials of the computer or rangekeeper so that no corrections in elevation are introduced by its mechanism.
8. If the test is to be performed with the boresight telescope, install it. If the gun sights are to be used (the normal procedure), they must have been boresighted recently. Set a positive value of sight angle at the gun and record this setting. The purpose of setting in this sight angle is to ensure that the elevation reading of

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the gun will be higher than that of the director at all bearings.

9. Train the director to a given bearing; elevate or depress the director line of sight so that it will move across the horizon as the ship rolls. Record for later reference the value of director elevation used on each bearing.

10. Train the gun to the same bearing as the director.

11. The gun pointer depresses his gun until it is approximately on the horizon. When the director sight crosses the horizon, the director pointer calls "Mark," and the gun pointer turns his handwheels until his line of sight crosses the horizon simultaneously. When he is on, he checks back to the director exactly on the mark, so that when either one calls "Mark" the other will be exactly on the horizon. To eliminate lost motion, always move the director and gun lines of sight onto the horizon from the same direction.

12. When the gun is on, read and record both the mechanical and the follow-the-pointer dials. The follow-the-pointer dials will read the total uncorrected gun error, and this should equal the difference between the director elevation and the gun elevation as read from the mechanical dials.

13. Repeat the foregoing process at 10° or 15° intervals throughout the training arc of the gun.

14. Obtain the uncorrected gun error by subtracting the director elevation from the gun reading (never the reverse), and record the result for each bearing.

A sample of data obtained in this way follows:

Bearing	Gun	Director	Difference (uncorrected gun error)
0°	1990	1976	14
15°	1991	1979	12
30°	1993	1982	*11
45°	1993	1981	12
60°	1991	1978	13
75°	1990	1974	16
90°	1988	1968	20
105°	1987	1963	24
120°	1988	1960	28
135°	1990	1958	32
150°	1988	1951	37
165°	1990	1950	40
180°	1992	1950	42
195°	1990	1946	44
210°	1991	1946	**45
225°	1992	1948	44
240°	1991	1948	43
255°	1995	1955	40
270°	1994	1957	37
285°	1995	1963	32
300°	1993	1965	28
315°	1990	1966	24
330°	1987	1968	19
345°	1988	1972	16
360°	1990	1976	14

*High point.
**Low point.

The data tabulated above are plotted by the method shown in figure 7D2. Note that the difference between gun elevation and director elevation varies with different angles of train. If the roller path compensator had been properly set (no uncorrected inclination), these differences would have been constant and the data would plot as a straight line. As it is, however, the differences vary, indicating uncorrected inclination, and the data will therefore plot as a sine curve. Note that the example shown here is for the full 360° arc of train, which is a condition almost never realized in practice. Hence, while both a high point and a low point are shown on our sample curve, only one of these points may be present on the curves obtained in an actual installation.

After plotting and drawing the curve, find the zero axis (i.e., the curve's axis of symmetry, which is parallel to the abscissa or x-axis). Either of two methods may be used:

1. If both the high point and the low point have been plotted, add the high point and low point values, and divide by 2. The resulting value is the ordinate (y-axis value) through which the zero axis passes. Plot this either on the y-axis or on the curve, and draw a line through it parallel to the abscissa. You have now drawn the curve's zero axis.

2. The alternate method, which is usable if either the high or low point has been plotted, is to take a point on the sine curve 90° from the high point or the low point, and draw through it a line parallel to the abscissa.

The distance of the zero axis above the abscissa represents the error due to all causes other than roller-path inclination. Figure 702 shows how this error is broken up into component parts. Sight angle and dip correction are known values; the remaining error represents

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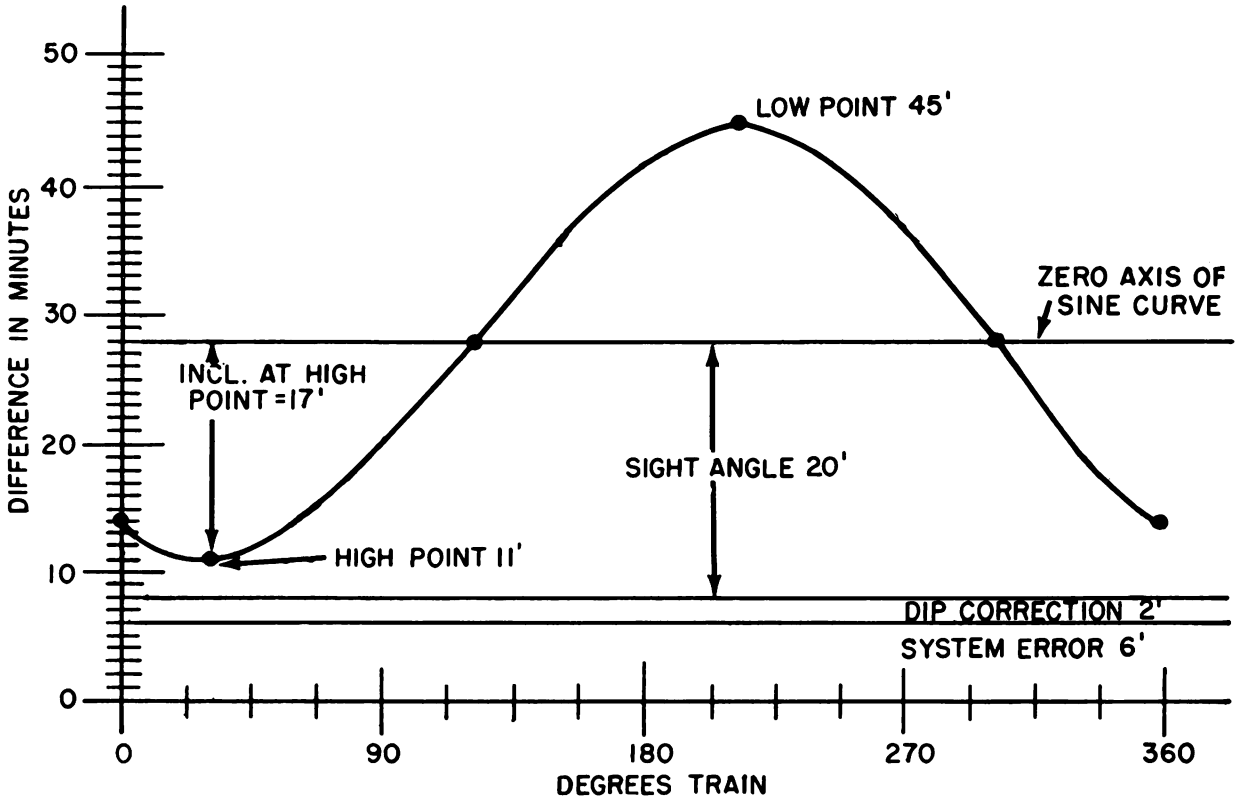

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Figure 7D2.—Sine curve plot of horizon check data.

the system error. This constant system error can be removed by adjustment of the elevation response at the gun. When this is done, tram values in elevation will have to be corrected.

The low point of the curve represents the bearing and inclination of the high point of the gun roller path, with respect to the reference plane (in this case, the director roller path). If no low point is shown on the plotted curve, it may easily be calculated, since it would occur at a bearing 180° from the high point of the curve. Further, it would occur at the same distance from the zero axis of the curve as did the high point. The bearing of the low point of the curve represents the bearing of the high point of the gun roller path. The distance of the low point below the zero axis of the curve represents the inclination of the gun roller path. In the example shown in figure 7D2, the high point of the gun roller path (represented by the low point of the sine curve) is at 30° train, and the inclination at that point is 17 minutes. Thus, for this example, the following desired data are available:

Bearing of high point ..... 30 degrees
Inclination of high point..... 17 minutes
Constant error of system ..... 6 minutes

Note that the low point of the sine curve is the high point of the gun's roller path. We know that the uncompensated roller path inclination plots as a sine curve. When the gun is trained to the highest point on its roller path, the actual gun elevation to the horizon will be at its lowest valve with respect to the reference plane. This occurs because the gun's roller path has not been completely corrected to the reference plane. In other words, the high point of the gun's roller path has raised the gun above the reference plane, and to elevate to a given target now requires less elevation angle between the gun bore axis and the gun roller path. With gun elevation at its lowest value, the difference between gun

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and director elevation will be a minimum; a minimum difference is the low point of the sine curve.

7D6. CALCULATING CORRECT COMPENSATOR SETTING

The horizon check is usually made with some setting already on the roller-path tilt compensator. The tilt found by the check, therefore, is not the total inclination but only the uncorrected inclination. It is an additional inclination to that for which the compensator has been set. This newly discovered inclination must be added vectorially to the inclination previously known to exist, in order to determine the total inclination for which the compensator must be set. This may be done graphically, as shown in figure 7D3. In this figure the results obtained previously were used to illustrate the method, which is as follows:

1. The line OA is drawn to represent zero train.

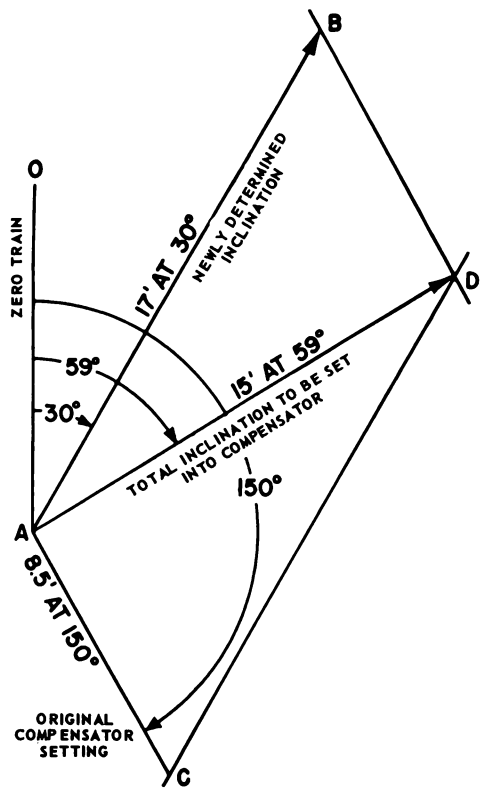

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Figure 7D3.—Compensator-setting calculation.

2. The original setting of the compensator (8.5' at 150°) is plotted as line AC. This is done by measuring off the angle clockwise from OA, and measuring the inclination on that line to a convenient scale.

3. The inclination found (17') is plotted as AB on bearing 30 degrees.

4. CD is drawn parallel to AB, and BD is drawn parallel to AC. These lines intersect at D.

5. A line AD is drawn from the origin to D. This line represents the total inclination. Its bearing (59°) and length (15') may be read according to the previously established scale. These are the data that must be set into the compensator.

It should be noted that compensators are constructed to read the error rather than the correction. Thus, if the error is 15' at 59°, the bearing scale is turned to 59°. Then the inclination of 15' is set on the inclination scale, and the adjustment is completed.

7D7. SIMPLE ELEVATION CHECK

When at sea, it is desirable to perform a simple elevation check at frequent intervals. The method is the same as that in the horizon check, except that each gun is checked at only one point on the horizon. The difference between gun and director reading after correction for sight angle should equal the dip correction. If it does not, an error of some sort is present and must be investigated. Before undertaking a complete horizon check as a result of such disagreement, however, check to see that the transmission system is functioning properly, and that the roller-path tile compensator is at its proper setting, both for bearing and for inclination.

7D8. CHECK OF AUTOMATIC FOLLOWUP SYSTEM

After a battery has been aligned in elevation, a test of the automatic followup system should be made. This involves training on a target, setting up the problem in the computer and positioning the gun in automatic (using computed gun orders), setting the sights according to generated sight angle and sight deflection, and checking to see whether the gun telescopes are on target. If they are not on, the amount that Vs and Ds must be changed from the computed values to bring the sights on the target represents the error of the system. To eliminate trunnion tilt errors when this test is made, it should be done when there is little or no roll.

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The preceding discussion of battery alignment has dealt only with gun batteries. Proper alignment is equally important in any other director-controlled battery such as torpedo, missile launcher, etc.; but the methods used will vary with the characteristics of the battery to be aligned.

E. Firing Cutout Mechanisms

7E1. GENERAL

In terms of the definition of battery alignment at the beginning of this chapter, the battery is aligned when, with the dials matched and parallax on zero, all the lines of sight and the axes of all gun bores are parallel, regardless of the ordered angles of gun train and gun elevation. In practice, however, the battery check is not complete until: (1) the firing cutout cams in each gun have been plotted, cut, and installed; and (2) the firing cutout mechanisms have been checked, with the cams installed, to ensure that both the mechanical and the electrical firing circuits are interrupted properly whenever the guns move from a zone of safe fire to a danger zone.

Firing cutout mechanisms are designed to interrupt the mechanical and electrical firing circuits whenever the guns are trained or elevated to a position where firing the guns would endanger ship's personnel or damage own ship. They should not be confused with the frameworks of steel tubing or depression-stop cams that are used to limit the movement of some light machine guns to safe zones of fire. Firing cutout mechanisms do not interfere with the free movement of the gun; this is done by the train and elevation limit stops.

The Bureau of Naval Weapons has issued strict mandatory instructions, summarized in the next article below, for the guidance of the personnel responsible for plotting, cutting, installing, and checking firing cutout cams and mechanisms. In addition, special instructions not detailed here govern particular gun installations.

The importance of firing cutout mechanism layout, adjustment, and maintenance is difficult to overemphasize. Many casualties in which a ship's guns have fired into her own structure have been traced to neglect of firing cutout mechanisms, or they have resulted from somebody's deliberate bypassing of these mechanisms. Every one of these casualties could have been prevented if the firing cutout mechanism had functioned properly. As was pointed out in the first chapter of this text, safety is a universal objective in all procedures relating to ordnance and gunnery. That is why firing cutout mechanisms must function effectively in all mounts and turrets in which they are installed.

7E2. BUWEPS REGULATIONS FOR FIRING CUTOUT CAMS

Firing cutout mechanisms are designed to prevent firing into permanent parts of the ship's structure. In plotting the firing cutout cam, all removable parts of the ship's structure such as stanchions, handrails, lifelines, chests, and lockers are disregarded. Such movable equipment as boats, cranes, booms, davits, and hatches are secured in such a manner as to obstruct the line of fire as little as possible. The firing cutout cam is plotted around this secured position of the equipment.

Personnel, such as other gun crews and lookouts, that are stationed within the possible line of fire must be protected by the cutout cam; however such personnel are not normally protected against blast danger. In order that the firing cutout cam may be designed for the maximum possible zone, the Bureau of Naval Weapons does not approve of cutting cams to protect forestays, halyards, radio antennas, and such top hamper. Peacetime target pratice must be arranged so as to keep the fire clear of these obstructions. In wartime these hazards must be accepted.

The minimum clearance to be maintained between the extension of the axis of the gun bore and the fixed structure of the ship varies with different size guns. One reason for this is the lag between the time the cutout mechanism functions and the time the guns actually cease firing. For protection of the other installations, the minimum clearance is computed with the other guns and directors at zero degrees elevation and the angle of train at which they are normally secured.

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Missile launchers for Terrier, Tartar, and Talos missiles are equipped with firing cutout devices of the type normally used in gun mounts. Terrier and Tartar launchers have an automatic blind zone cutout system incorporated in the missile launcher power drive to prevent pointing a loaded launcher within the nonfiring zones as determined by the ship's structure. Talos launchers also have a blind zone cutout system, similar to that on Terrier launchers, to prevent physical interference of missiles on the launcher with the ship's structure, but not to prevent pointing missiles at the ship's structure. Firing into the ship's structure is prevented by firing cutout devices, as on gun mounts.

7E3. TURRET FIRING CUTOUT MECHANISMS

The majority of turrets with 6-or-8-inch gun bores have separate firing cutout mechanisms for train and for elevation. In train the cam surface is fastened to the stand near the roller path, while the plunger and cutout switch are located on the move with the carriage. Cutout action is obtained by securing cam surfaces to the stand at those related bearings coincident with the danger zones of fire. The elevation cutout is a flat cam-and-plunger mechanism mounted on the deck lug of the gun. Movement of the gun in elevation, through a mechanical connection, rotates the cam.

On these large-caliber guns only the electrical firing circuit is interrupted by the cutout cams. The percussion firing circuit is not cut out by the cams; however, warning lights are energized in the mount or turret to indicate that the gun is in a danger zone and should not be fired by percussions.

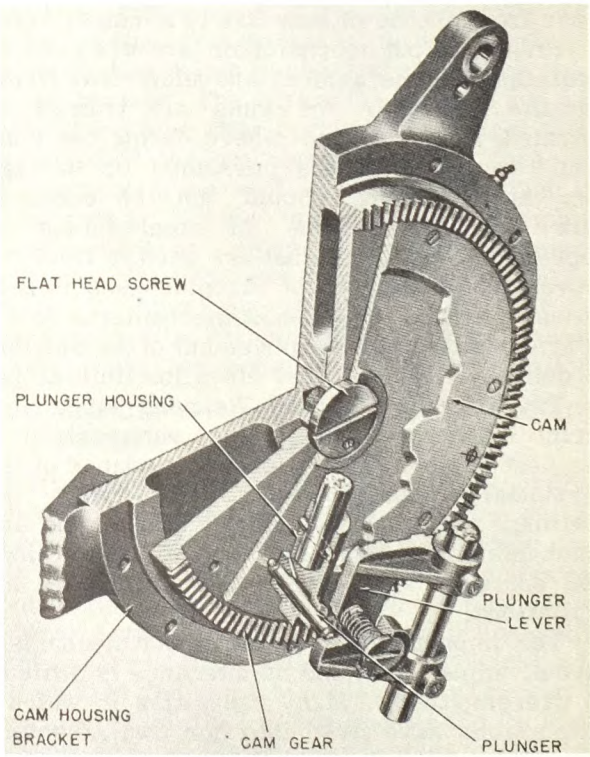
The proper settings for these firing cutout mechanisms are outlined in the applicable OPs. Usually the OPs will list the settings for the individual turrets in ships of a class. After the cams are installed, they must be checked by the methods similar to those outlined for smaller guns.

7E4. MOUNT FIRING CUTOUT MECHANISMS

All mounts of 5-inch caliber and smaller incorporate mechanisms wherein one cam, referred to as a profile cam, controls the firing circuit when the gun is in or near a danger zone of fire in either train or elevation. The mechanical action of these mechanisms differs slightly from gun to gun, but in principle they are the same and can be considered collectively.

The cutout feature of profile-cam firing cutout mechanism is accomplished by the action of a plunger or cam follower on the face of a disc-shaped profile cam. When the plunger rides up on a high point of the cam, which represents a danger or nonfiring zone, it pushes against the plunger lever, which in turn causes sufficient movement of another lever or levers to interpose a break in the firing circuit. In most guns, this movement interrupts both the electrical and the percussion firing circuits.

Figure 7E1 shows a cutaway view of a typical firing cutout mechanism plunger and profile cam; this one is from a 5"/54 mount. The cam is turned by gun train order at one-to-one speed, while the plunger mechanism moves radially from near the center to the edge of the cam in accordance with gun elevation order. A point near the center of the cam represents maximum gun elevation, and the outer edge minimum gun elevation.



53.131

Figure 7E1.—Cutaway view of firing cutout mechanism plunger and cam.

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The rise from cutaway area to the raised portion of the cam is a 30° incline. This permits the plunger cam follower to ride from the low surface of the completed cam to the high surface without excessive wear or scoring. Cutout occurs when the plunger is two-thirds of the way up the incline. A switch opens the firing circuit, and a mechanical clutch disconnects the linkage to the firing mechanism from the firing pedal.

7E5. PLOTTING, CUTTING, AND INSTALLING THE CAM (PROFILE CAM MECHANISM)

Since the contour of the cam determines where the gun can and cannot fire, it is obvious that the most critical step in firing cutout mechanism installation is concerned with plotting and cutting the cam's contour. By far the most important kind of firing cutout mechanism is the profile cam type; therefore the plotting and makeup of this type only will be discussed in this chapter.

The entire firing cutout mechanism, with the exception of the profile cam itself, is assembled and installed on the mount during manufacture. The profile of the cam depends on the obstructions presented from the point of view of its location after installation; hence the cam profile can be determined only after installation. It is necessary first to determine the safe firing zone, i.e., the locus of all gun positions in which firing may be safely performed in accordance with BuWeps standards. This zone must be plotted in such a way that it is immediately unable as a guide in shaping the cam itself. The plot is then transferred to the cam plate blank and cut into the blank. The last step is installation of the cut cam and verification of its proper functioning. Here is the step-by-step procedure, in brief:

1. Install a boresight in the gun barrel, and sight through it to establish, for each successive 5° increment of train angle, the lowest (and, if applicable, the highest) elevation angle at which it is safe to fire, in accordance with BuWeps standards.
2. As these elevation and train angles are determined, they must be tabulated and plotted on a special polar-coordinate form illustrated in figure 7E2. Note that a different form is issued for each caliber, mark, and mod of gun, and even for the right- and left-hand guns in a twin mount (because their cams turn in opposite directions).
3. Transfer the plot to another copy of the plotting sheet to make a smooth copy. See the OP or OD on the gun for such information as minimum radius of curves, how wide the cam slope should be, etc. Verify the plot for accuracy.
4. Let the cam be cut in accordance with the verified plot. This is generally done by a navy yard machine shop, not by ship's personnel.
5. Install the cam and check it throughout all angles of train to verify that it complies with BuWeps standards. This can be done by positioning the gun with boresight in place as in step 1, and checking the functioning of the firing circuit and mechanical firing linkage, using a firing circuit test lamp to check the circuit and observing the functioning of the linkage.

For details on the procedure for any specific mark and mod of mount, see the OP or OD on the equipment.

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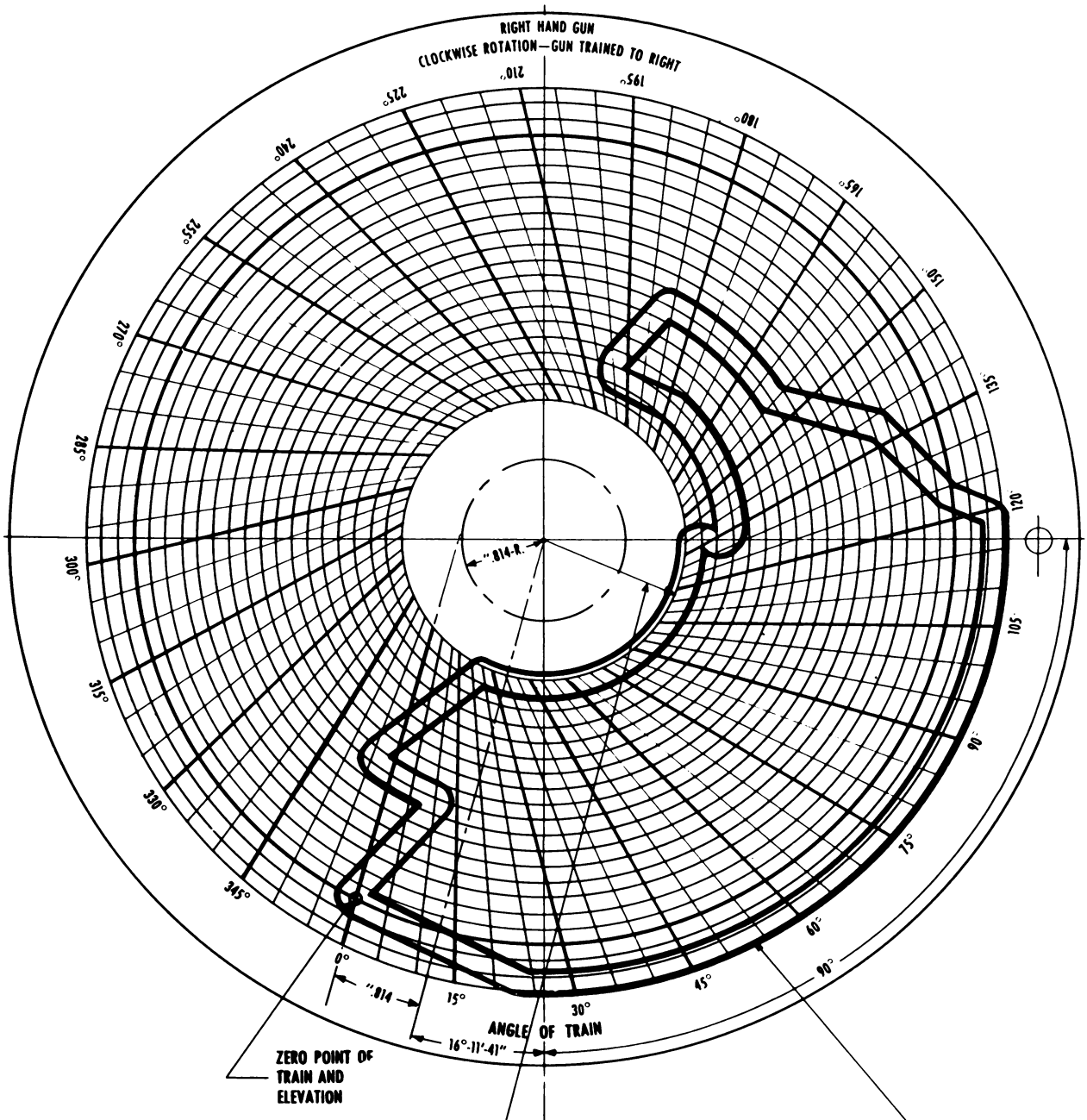

85°	ELEVATION	=1".434–RAD.	30°	ELEVATION	=3".032–RAD.
80°	"	=1".567– "	25°	"	=3".185– "
75°	"	=1".704– "	20°	"	=3".338– "
70°	"	=1".845– "	15°	"	=3".491– "
65°	"	=1".988– "	10°	"	=3".645– "
60°	"	=2".133– "	5°	"	=3".800– "
55°	"	=2".280– "	0°	"	=3".954– "
50°	"	=2".428– "	5°	DEPRESSION	=4".109– "
45°	"	=2".578– "	10°	"	=4".264– "
40°	"	=2".729– "	15°	"	=4".420– "
35°	"	=2".880– "			

Figure 7E2.—Simple cam plotting sheet. 53.132

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CHAPTER 8

SPOTTING AND NAVAL GUNFIRE SUPPORT

A. Elements of Spotting

8A1. INTRODUCTION

The chapter's subject matter is largely concerned with gunnery operations, rather than with principles of weapons and associated equipment. In studying it, bear in mind that operational methods and techniques are broadly determined by the Chief of Naval Operations, and are published as doctrine in NWPs, NWIPs, and related publications, as described in chapter 1, and by other responsible command echelons. The material in this chapter is not intended to supplant such sources of doctrinal information.

This chapter takes up the problem of gunfire control where chapter 5 left off, and goes on to discuss certain advanced aspects of fire control in the special situation where naval guns are used against targets ashore, particularly in connection with amphibious attacks.

As chapter 5 stated, not all the factors which affect the flight of a projectile can be precisely evaluated in advance of firing. Even with the best fire control equipment available, experienced gun crews, and efficient fire control personnel, the opening shots may not hit the target. It is therefore necessary to apply corrections (spots) to the initial firing data to bring the shots on the target. The corrections are applied to gunlaying data for subsequent rounds fired. This technique is called spotting.

8A2. DISPERSION AND ITS CAUSES

The problem of spotting is complicated by dispersion. If a battery of guns is fired at the same instant with the same settings in range and deflection (this is salvo fire), the projectiles will not all land at the same point, but will be dispersed over the vicinity.

If the battery of guns were stationary and rigidly fixed in elevation and train, variations in range and deflection would be caused by (1) differences in weight and temperature among individual powder charges; (2) differences in projectile weights; (3) variations in angles of projection (the longitudinal axis of projectiles diverge, in varying amounts, from the continuation of the bore axis as they leave the guns); (4) differences in projectile seating, causing variations in density of loading and initial velocity; (5) differences in erosion among the several guns, with corrections not precisely made. Such causes as these make a certain minimum amount of dispersion inevitable. There are other causes of dispersion which can be prevented. The motion of the ship may result in the pointers and trainers of guns to be off target when the guns are fired. The same effect may result from failure to fire exactly simultaneously, causing different guns to fire at slightly different points in the roll.

Director-controlled gunfire, although not subject to the same characteristic errors as pointer fire, is subject to its own set of characteristic errors. All such errors are considered accidental errors. They are revealed by analyses of firings, and their effects are governed by the laws of probability.

For discussion of the laws of probability in general the student is referred to any good text on the subject. Elementary discussions of probability will also be found in most textbooks on statistics. This chapter is primarily concerned with the practical aspects as applied to spotting of gunfire.

8A3. DEFINITIONS

The terms defined below relate to gunfire and spotting:

SLOW FIRE. In slow fire, firing is deliberately delayed to allow for application of spots, or to conserve ammunition.

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RAPID FIRE. In rapid fire, firing is NOT delayed to apply corrections.

SALVO. A salvo consists of one or more shots fired simultaneously by the same battery at the same target.

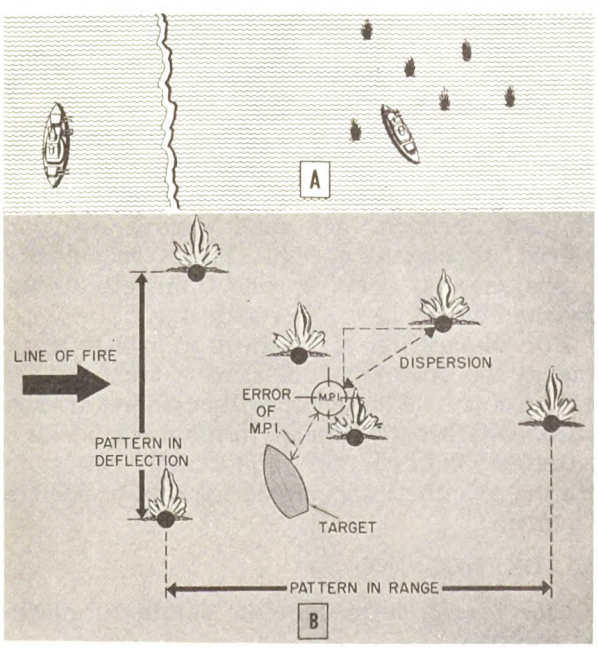
SLOW SALVO FIRE. In slow salvo fire, the guns are loaded on command and fired together at a fairly slow rate.

RAPID SALVO FIRE. In rapid salvo fire, the guns are loaded on command and fired together at a RAPID rate. (Both slow and rapid salvo fire are used to establish a hitting range to a surface or land target.)

RAPID CONTINUOUS FIRE. Rapid continuous fire is the fastest firing method for 5" guns. The pointer's firing key is locked in the closed position, and the rate of fire depends only on the loading speed.

RAPID PARTIAL SALVO FIRE. Rapid partial salvo fire for a turret (6" and above) is synonymous with rapid continuous fire for a 5" gun. (Both of these types of fire will most often be used after the hitting range has been established or, in the case of the 5" gun, against aircraft.)

MPI. The Mean Point of Impact (MPI) is the geometric center of the points of impact of the various shots of a salvo, excluding wild shots (fig. 8A1).



53.119

Figure 8A1.—Salvo pattern.

WILD SHOT. A wild shot is a shot with an abnormally large dispersion in range, or deflection, or both.

In general the dispersion of a wild shot is too great to have been caused by any of the accidental errors mentioned in article 7A2, above. For example, if a sightsetter were to set a range of 15,000 yards instead of the correct range, 10,500 yards, the result would be considered a wild shot.

PATTERN. The pattern of a salvo is the area covered by the points of impact of the shots (except wild shots). The pattern in range is the distance measured parallel to the line of fire between the point of impact closest to the battery and the one farthest away, excluding wild shots. The pattern in deflection is the distance, measured at right angles to the line of fire, between the point of impact farthest to the right and the one farthest to the left, excluding wild shots.

DISPERSION. The dispersion of a shot is the distance of the point of impact of that shot from the MPI. Dispersion in range is measured parallel to the line of fire, and in deflection at right angles to the line of fire, in a horizontal plane. Dispersion in range is positive when the shot falls beyond the MPI. Dispersion in deflection is positive when the shot falls to the right of the MPI. The algebraic sum of the dispersions in range (or deflection) of the several shots of a salvo must equal zero. (See definition of MPI.)

APPARENT MEAN DISPERSION. The apparent mean dispersion of a salvo in range (or deflection) is the arithmetical average of the dispersion in range (or deflection) of the several shots of the salvo, excluding wild shots.

TRUE MEAN DISPERSION. The true mean dispersion is the arithmetical mean of the dispersions in range (or deflection) of an infinite number of shots, all assumed to have been fired under conditions as nearly the same as possible and excluding wild shots.

HITTING SPACE. Hitting space (usually measured only in range) for a target is the distance behind the target (measured parallel to the line of fire) that a shot through the top of the target will strike the horizontal plane through the base of the target (fig. 8A2). It includes the projection of the target's vertical height upon the plane of the water plus the target's horizontal dimension in the line of fire (or depth). Hitting space in deflection is the angle subtended by the target.

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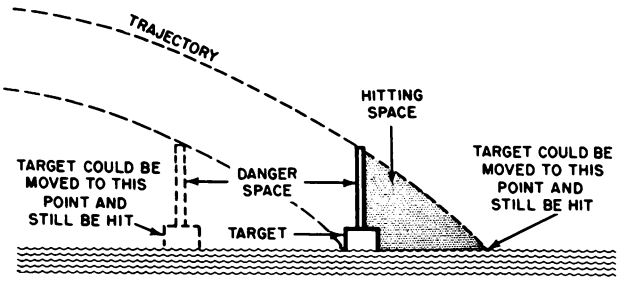


92.57

Figure 8A2.—Hitting space and danger space in range.

DANGER SPACE. The danger space for a target is the distance in front of the target, measured parallel to the line of fire, that the target could be moved toward the firing point, so that a shot striking the base of the target in its original position would strike the top of the target in its new position (fig. 8A2). At most ranges, danger space is virtually equal to hitting space.

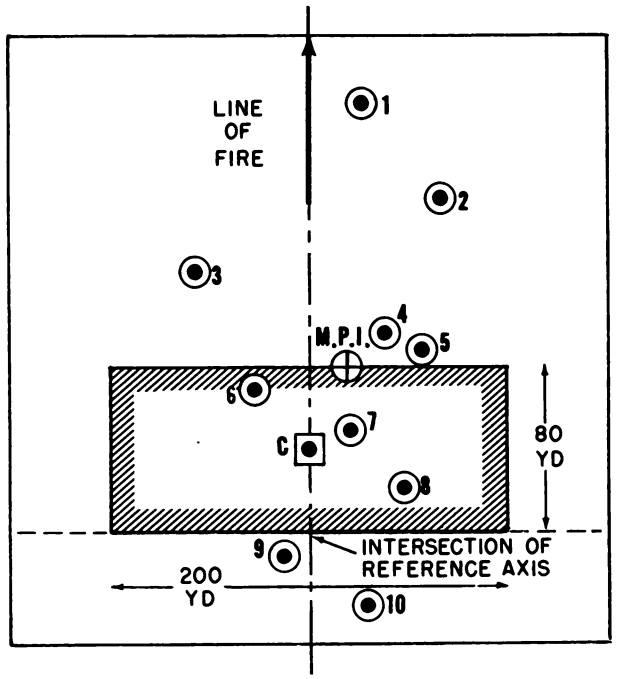
STRADDLE. A straddle is obtained from a salvo in range (or deflection) when, excluding wild shots, some of the shots of that salvo fall or detonate short of the target, and others beyond, (or right and left, respectively, for deflection). The target in figure 8A1, part A, is straddled.

ERROR OF MPI. The error of the MPI is its distance from the target (fig. 8A1) or other reference point, such as the center of the hitting space, measured (in a horizontal plane) parallel to the line of fire for range and at right angles to the line of fire for deflection.

8A4. DETERMINING LOCATION OF MPI

The definitions above will now be illustrated by an example (NOT to be considered typical) representing a salvo from ten 5''/38 caliber guns fired at range 8,500 yards against a target 40 feet high, 600 feet long, and with a beam of 90 feet. The target is situated with its length at 90° to the line of fire (fig. 8A3).

The danger space at this range, from column 7 of the range table (Appendix B, part 3), is 40/20 x 25 = 50 yards. Since the target "depth" is 90 feet, or 30 yards, the actual danger space is thus 50 + 30 = 80 yards. For most battle ranges the value of hitting space is the same as that for danger space. Hence hitting space is also 80 yards. Figure 8A3 represents the plan view of the target shown in terms of hitting space, an area 80 yards in range and 200 yards in deflection. The center of the hitting space is at C. (The fact that the target is not rectangular will be ignored.) The points of impact of the several shots are indicated by numbered dots and are identified by table 8-1, which gives the location of each impact from the reference axes, in this case taken as intersecting at the center of the target's waterline.



110.90

Figure 8A3.—Salvo analyzed in articles 7A4 and 7A5.

The location of the MPI is determined by measuring the distance, in range and deflection, of the point of impact of each shot from convenient coordinate axes, and finding the mean of these distances. It is convenient to refer impacts to axes intersecting at the center of the target's waterline, as was done in the table. The mean of these distances is 80 yards over and 20 yards right, which locates the MPI 80 yards beyond and 20 yards right of the center of the waterline.

If we assume that the error of the MPI is its distance from the center of the hitting space, this is seen to be 40 yards over and 20 yards right.

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Table 8-1

Shot No.	Distance from reference axes			
	Range yd		Deflection yd	
	Over	Short	Right	Left
1	220	------	30	------
2	170	------	70	------
3	130	------	------	60
4	100	------	40	------
5	90	------	60	------
6	70	------	------	30
7	50	------	20	------
8	20	------	50	------
9	------	10	------	10
10	------	40	30	------
Sum	850	50	300	100
	50	------	100	------
Diff	800	------	200	------
Mean	80	------	20	------

110.87

Inspection of figure 8A3, or of table 8-1, shows that the pattern of this salvo is 260 yards in range and 130 yards in deflection.

8A5. DETERMINING APPARENT AND TRUE MEAN DISPERSION

In determining apparent mean dispersion, remember that it is the arithmetical mean of the dispersions of the several shots, without regard to sign. Once the MPI position has been plotted, the several points of impact are now referred to the MPI to determine individual dispersions and apparent mean dispersion, as shown in table 8-2.

Apparent mean dispersion, based on 10 shots, is, according to table 8-2, 62 yards in range and 32 yards in deflection. Based on such a limited number of observations, it is unlikely to be a true measure of accuracy of fire. The true measure of accuracy is the mean dispersion of an infinite number of shots, all fired under the same conditions. This is the true mean dispersion. It is obviously impossible to

Table 8-2

Shot No.	Dispersion	
	In range yd	In deflection yd
1	140	10
2	90	50
3	50	80
4	20	20
5	10	40
6	10	50
7	30	0
8	60	30
9	90	30
10	120	10
Sum	620	320
Mean	62	32

110-88

measure this value experimentally by firing an infinite number of shots, but a theoretical value can be found in the relation

$$(7A) \quad D = D' \sqrt{\frac{n}{n-1}}$$

in which D is the true mean dispersion, D' the apparent mean dispersion, and n the number of shots from which D' was obtained. Table 8-3 gives the values of the ratio of D to D', i.e., values of

$$\sqrt{\frac{n}{n-1}}; \text{ for salvos of from 2 to 12 shots.}$$

The true mean dispersion, in the above case, is found by multiplying the apparent mean dispersion by 1.054. Hence the true mean dispersion in range is 62 x 1.054 = 65 yards, and in deflection is 32 x 1.054 = 34 yards.

Proof of the relation stated in (8A) is beyond the scope of this course.

8A6. SPOTTING MPI TO CENTER HITTING SPACE

Wide dispersion is apparent in the 10-shot salvo pictured in figure 8A3. Mathematically, however, it is correct spotting procedure to spot the MPI to the center of the hitting space. Shots 4, 5, 6, and 7 would be hits if the MPI

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Table 8 - 3

Number of shots in salvo	Ratio of true mean dispersion to apparent mean dispersion
12	1. 044
11	1. 049
10	1. 054
9	1. 061
8	1. 069
7	1. 080
6	1. 095
5	1. 118
4	1. 155
3	1. 225
2	1. 414

110.89

were spotted to point C. Shots 8, 9, and 10 would fall short of the target, while 1, 2, and 3 would still be long. Therefore the next salvo should include at least four hits and probably would have more, since dispersion as already noted is subject to many variables. Spotting the MPI to the center of the hitting space is a mathematical attempt to reduce the effect of dispersion variables.

As range increases, hitting space decreases and dispersion increases, the probability of hitting decreases. An officer detailed to duties which include spotting should know the dispersion at various ranges up to the maximum range of his battery. He can then determine the probability of hitting a target.

8A7. DESIRABLE PATTERN SIZE

If the MPI is at the desired point of impact, a pattern of small dispersion can be expected to yield the maximum number of hits. Where excessive errors creep in, however, excessive dispersion results. If the pattern is so spread that few shots are grouped around the desired point of impact a minimum number of hits is probable. From the standpoint of a maximum number of hits, it would seem desirable to eliminate errors completely so as to have a zero pattern in range and deflection. Such a pattern would be desirable if the MPI were always at the desired point of impact. It is difficult in actual firing, however, to place the MPI at this desired point. Since it would be better to hit with some of the shots than to miss with all, a larger pattern size is better.

In the Naval Warfare Information Publication, NWIP 22-2, there are tables giving the average pattern sizes for the various caliber guns. These tables were constructed from firings conducted at the Naval Weapons Laboratory. Patterns in the fleet should be no larger than those given in the tables.

8A8. ACCIDENTAL ERRORS CAUSING SHIFT OF MPI

Since dispersion of individual shots is caused by unpredictable errors, it is logical to assume that no two salvos will be exactly alike. Hence, the MPI of the shots of a given salvo can be expected to differ in location from the MPIs of other salvos.

The average shift between successive MPIs is usually so small as to be difficult for the spotter to estimate. Therefore, the spotter should not be too quick to spot when only one or two salvos seem to wander off the target during a string that is, in general, satisfactory.

8A9. CONTROL ERRORS

The only accidental errors so far considered have been those which affect individual guns of a battery. These are known as gun errors and should be distinguished from another class of accidental error which affects the battery as a whole. These are known as control errors and include errors in computing, transmitting of data to the guns, and in director fire, director pointing errors. They are not reflected in increased pattern sizes (i.e., increased dispersion among the guns) but are characterized by increased dispersion or error of the MPIs themselves.

There are four general control inaccuracies which may cause MPI error. These are listed in the order of probable frequency of occurrence and magnitude of effect:

1. Computer set up with incorrect values.
2. Ballistic corrections based on incorrect values (I.V., wind, air density, and others).
3. Battery not properly aligned with director.
4. Indeterminate errors ("Class B" and personnel errors).

Let us now consider each of these sources of control errors.

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8A10. INCORRECT COMPUTER SETUP

Determination of target course and speed is made directly from the spotter's estimate of target angle and speed, from CIC, or by rate controlling. Correct values of these two variables are difficult to determine; they are the chief cause of incorrect computer setup, and hence the chief source of MPI error.

Present range to target is valid only so far as its measurement is accurate. An error in basic range measurement directly causes an error in MPI.

Measurement of own-ship course and speed usually are reasonably accurate, but any inaccuracies result in an error in MPI.

8A11. INACCURATE BALLISTIC CORRECTIONS

The computer determines corrections for variations from standard conditions. Determination of these corrections based on incorrect values of ballistic wind, I.V., air density, etc., will give a total ballistic correction that will result in a corresponding error in MPI.

8A12. POOR BATTERY ALIGNMENT

Improper alignment between the guns of a battery results in greater dispersion and larger pattern sizes, but does not materially affect the error of the MPI of a salvo. In contrast, MPI error can be caused by misalignment between the controlling director and the battery as a whole. Such misalignment is generally caused by failure to director-check the battery and all directors. A battery aligned with one director is not necessarily aligned with another which may be in control. Frequent director checks can assist in elimination of this cause of MPI error.

8A13. INDETERMINATE ERRORS

There are two classes of indeterminate errors.

Some of the computations by mechanical computing elements in fire control instruments are only approximations of the true solutions. These approximations result in "Class B errors," which are small for normal ranges and therefore cause minimum error in MPI. However, at extremely short or long ranges the errors may become large, depending on the instrument concerned, and may seriously affect the MPI. When Class B errors are known to be large, they can no longer be treated as accidental, and steps must be taken to make correction for them.

The other class of indeterminate errors is assignable to control personnel. For example, the director pointer or trainer may be off the point of aim when the salvo is fired. Training and experience can reduce the magnitude of such mischance. Small errors of this type merely cause a slight shift of MPI and should not be corrected by the spotter. The director operator should inform the spotter of large discrepancies in the point of aim, so that the spotter may distinguish this error from others.

8A14. ERRORS AND THE SPOTTING PROCESS

It is not enough for the spotter to detect errors, estimate the spots required, and transmit them. He must be able to recognize the causes of errors by understanding their characteristics and knowing what to expect of the batteries he is working with, and then make up his spots with this information in mind. In summary, we list below the three main types of error that crop up in gunfire from shipboard, and what can be done about them.

1. Accidental gun errors causing dispersion of shots. These errors are only compensated to the extent of achieving desired pattern sizes. Most of the errors are eliminated by careful design, frequent checks of battery alignment, normal upkeep of the battery, and the training of gun crews.

2. Accidental gun errors causing a shift in the MPI of successive salvos. The shift in both deflection and range is usually small.

3. Control inaccuracies causing error of MPI. It is the primary duty of the spotter to "spot" the corrections in range and deflection necessary to bring the MPI of a salvo to the desired point of impact. He should recognize the first two classes of errors in order to spot the error of MPI caused by control inaccuracies.

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B. Functions and Duties of the Spotter

8B1. GENERAL FUNCTION OF THE SPOTTER

The primary function of the spotter is the correction of range and deflection errors of the MPI so as to bring the shots on the target. Prompt and accurate correction of initial errors may be the deciding factor in a naval engagement. He bases these corrections on his own observations combined with those of the fire control radar operator. As a rule, in good visibility the spotter will estimate the necessary deflection correction, and range corrections will be obtained from the radar. Under unfavorable conditions both range and deflection corrections will be obtained from the radar.

If radar fails, optical spotting must substitute. In the initial discussion of the spotter's problems, it will be assumed that radar is not available.

8B2. SPOTTER QUALIFICATIONS

A good spotter should have the following qualifications:

1. An even, calm temperament, not excitable under stress.
2. Sound judgment.
3. Decisiveness.
4. Alertness.
5. Normal eyesight, hearing, and speech.

8B3. GENERAL FUNCTIONS AND DUTIES OF SPOTTERS

Besides his primary function of correcting the fall of shot, there are other functions which the spotter must perform before and during firing. In general these are:

1. Describe the enemy forces (general bearing line, number of ships, deployment, etc.).
2. If he is also acting as the control officer, he estimates the values of range, target angle, and target speed, and keeps plot informed of all changes to these values.
3. Keep control informed of the tactical situation.

There are other duties which the spotter may be required to perform. Their exact nature will vary with different types of ships. The spotter's detailed duties and spotting procedures are prescribed in the ship's Weapons Department Organization Manual, and in fleet doctrinal publications. (NWIPs etc.)

8B4. VISUAL ESTIMATE OF TARGET COURSE AND SPEED

To arrive at a solution of the fire control problem, the computer must have target course and speed. Often the spotter can by observation through binoculars get these data.

To determine target course, the spotter must be able to estimate accurately target angle (i.e., relative bearing of own ship as seen from the target).

To estimate target angle the spotter must know the structural details of all likely targets. Silhouettes of all probable targets are furnished each ship. The spotter should study the details of these visual aids, not only for the purpose of recognizing the enemy, but also for estimating target angle. In estimating target angle, the spotter should make use of prominent objects such as bridges, breaks in the deck, stacks, masts, and other features. By observing the opening and closing of the apparent distance between such details, the spotter can estimate the angle the enemy ship makes with the line of sight.

Target speed can at best be only roughly estimated. Here again, knowledge of enemy ships is valuable, particularly as regards maximum speeds. Target speed may be estimated as about 1 or 2 knots less than the maximum speed of the slowest ship in the formation.

To make the best speed estimates you must have extensive training and experience. The aids used by a spotter in a direct estimation of target speed are smoke from the stacks, bow wave, and stern wake.

A spotter who knows his target size can also make accurate preliminary estimates of range by using the mil graduations in his binoculars. (See the next article for further explanation of mils.)

8B5. SPOTTING IN DEFLECTION

Because it is simpler to make range spots when there is no deflection error (this is particularly true at long ranges), the spotter customarily calls deflection spots first. The

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unit used in deflection spotting is the angular mil.

THE MIL AND HOW TO USE IT. You are already acquainted with the angular mil because it is the unit in which gunsight deflection scales are calibrated. There are about 6400 mils to a circle, and 1 mil is about 0.56°, or 3.37 minutes of arc. The reason for using the mil as an angular unit in measuring deflection, rather than using degrees or minutes, is that it has a very useful property: If a distant object appears to an observer to have an angular width of 1 mil, then the actual width of the object is 1/1000th of the range.

Telescopes, binoculars, and other optical devices for naval use often have reticles with mil scales etched on them. If you use such binoculars to look at, say, a 30-foot boat broadside on at a range of 1000 yards, the image you see in the binoculars will have an angular width of 10 mils. Figure 8B1 shows further graphical examples of the relationship between mils and range. Part A of the figure shows how 1 mil subtends different linear distances at different ranges, and part B shows several other examples of the relationship. To bring the use of mils down from this theoretical level, look at figure 8B2. What is the linear size in deflection of salvo A's pattern?

Salvo A at a range of about 11,500 yards subtends 5 mils. One one-thousandth of the range is 11.5 yards; multiplying by 5 (mils) gives an actual pattern width in deflection of 57.5 yards. As a practical matter, of course, it's absurd to specify a pattern width down to a half yard; rounding off, the answer would be about 58 yards.

In estimating deflection spots, use the target width in mils as a guide.

ALLOWING FOR SPLASHES. With a high-speed surface target, the spotter should bear in mind that the apparent MPI in deflection should be held abaft the point of aim to allow for target travel while the splashes are forming. Do not assume that full splashes form instantaneously at the impact of a salvo. The time lag is only a few seconds at most, but is sufficient to allow considerable movement of a fast target.

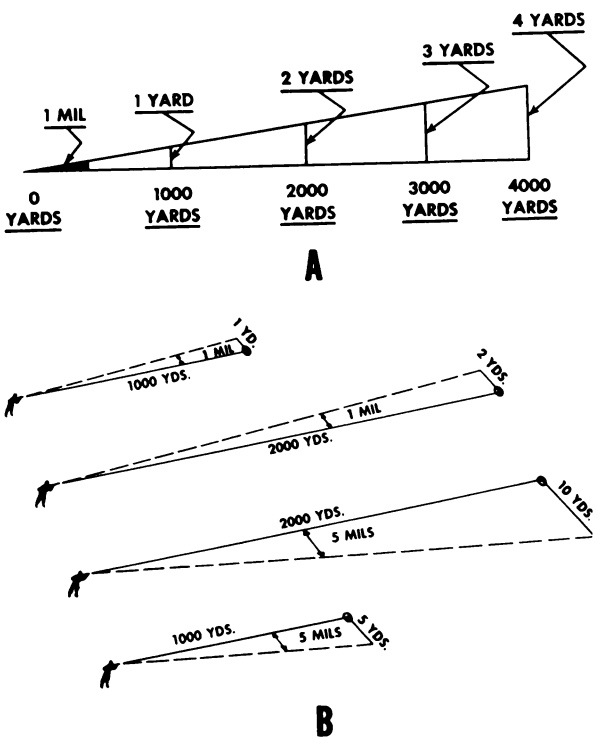

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Figure 8B1.—The angular mil and how it is used.

8B6. SPOTTING IN RANGE

Spotting in range is more difficult than spotting in deflection. There is no convenient angular measure that is uniformly applicable at all ranges, like the almost foolproof mil.

Figure 8B2 is adapted from a typical spotting diagram. It shows schematically how different ranges look to you as an observer 100 feet above the water surface. The lateral broken lines represent ranges in increments of 1000 yards; the diagonal broken lines represent angular mils; and the curved solid line at the right shows the apparent length in mils of a 600-foot broadside target at various ranges. Unfortunately, the natural seascape is not marked with these handy reference lines, but the diagram is a helpful guide in learning how to estimate ranges. It is used in conjunction with such training aids as miniature spotting boards, and with observation during target practice.

The range lines in figure 8B2 represent angular distance below the horizon at which any object would appear from a height of 100 feet, if observed on the corresponding range lines. The distances between the range lines represent the apparent range differences as viewed by an observer at the height (in this case 100 feet) for which the diagram was constructed.

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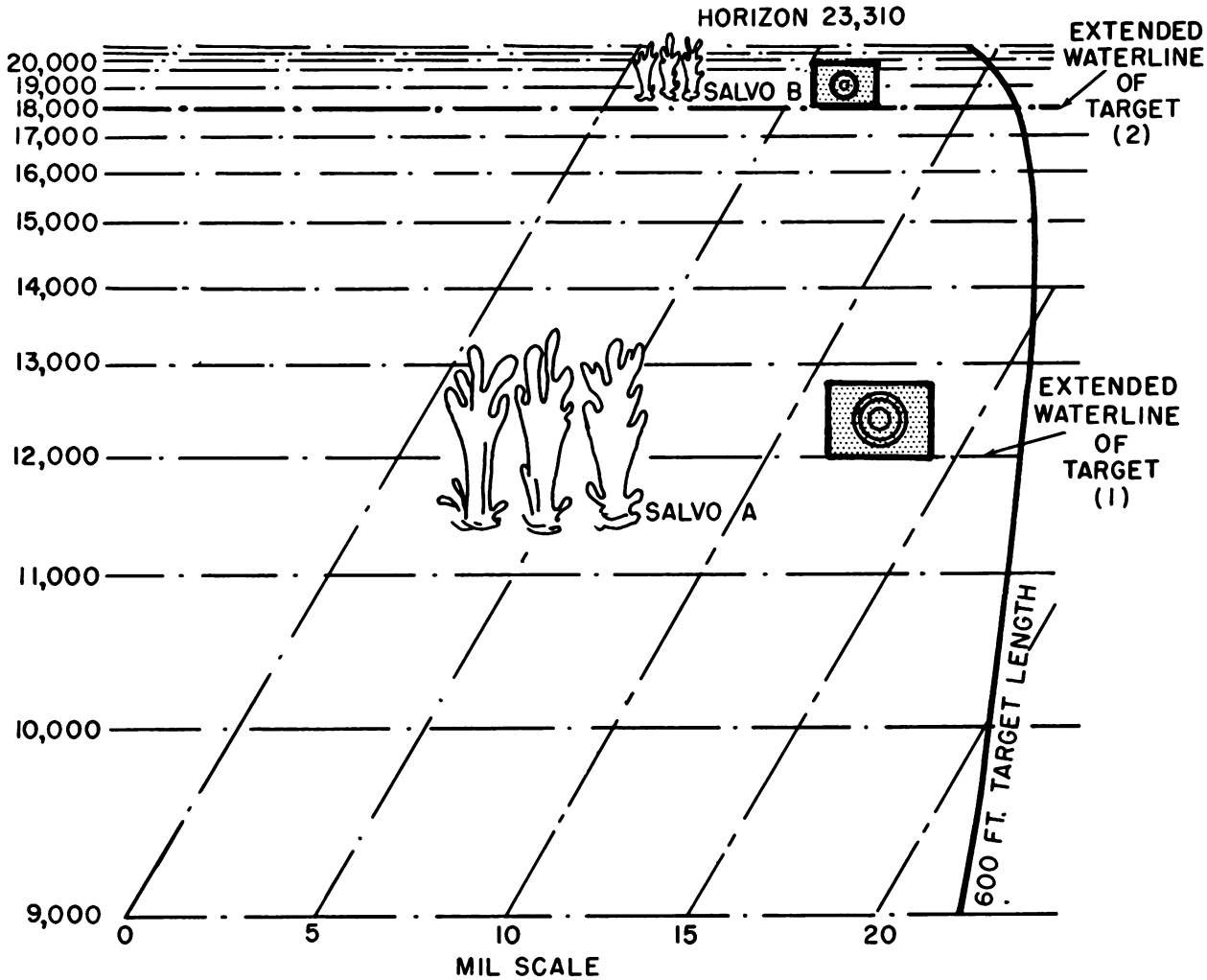

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Figure 8B2.—Practice diagram for range spotting.

A study of figure 8B2 shows that salvo A is clearly short, by about 500 yards, of the imaginary extension of the waterline of a target at 12,000 yards. However, the error of salvo B, fired at a target at 19,000 yards, is not so apparent. The 500-yard error of salvo B is difficult to see when compared with the extended waterline of the target. Thus, for shipboard spotting at such a range, the splashes must be in line with some portion of the target before the spotter can reasonably tell whether the salvo is over or short, to say nothing of estimating the amount of the error.

In addition to its use for estimating range and range errors, the spotting diagram shows the number of mils a given target length will subtend at any given range. For example, in figure 8B2 a 600-foot target will subtend 20 mils at 10,000 yards range.

One of the most common mistakes made by the untrained spotter is to underestimate the amount of range error at long ranges, because a given range error will subtend a much smaller angle at long ranges than it does at short ranges. However, with good visibility and from a height of 120 feet or more, the MPI error can usually be estimated with reasonable accuracy at ranges up to 15,000 yards, by observing the position of the bases or slicks of the splashes relative to the target waterline.

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C. Methods of Spotting

8C1. SPOTTING TERMINOLOGY AND MESSAGE PRACTICE

As in other operational communications, there is a prescribed terminology and message sequence for spotting. These are published in fleet operational directives which you will use on active duty. The examples below show the general practice at the present time.

SURFACE FIRE. For surface fire, only range and deflection are spotted. The correction necessary to bring the MPI on the target is given in the following terminology sequence.

1. Deflection correction—RIGHT or LEFT, in mils.
2. Range correction—ADD or DROP, in yards.

Where no correction is necessary, the designation NO CHANGE is used. Typical examples of spot transmissions by telephone are RIGHT 10, ADD 1,000, or DROP 500.

AA fire. For air targets, corrections to bring the burst on the target are needed in three dimensions. Even well-trained personnel find it almost impossible to estimate errors rapidly in three dimensions. AA spotting is therefore generally limited to correcting for obvious constant system errors.

The proper terminology for spotting in AA fire is as follows:

1. Deflection correction—RIGHT or LEFT, in mils.
2. Height-of-burst correction—UP or DOWN, in mils.
3. Range correction—ADD or DROP, in yards.

Deflection and evaluation spots will normally be made by the control officer. Range spots will be made by the rangefinder or radar operator.

NAVAL GUNFIRE SUPPORT. In shore bombardment, as in AA fire, spots in three dimensions may be necessary. The terms are the same as in the preceding paragraph, but the units are not the same. When naval guns are used to support landing operations, joint forces are involved. The Navy, Army, and Air Force have a standardized spotting terminology for joint operations which will differ from the above, in that all corrections for indirect fire are spotted in yards. At the computer, deflection and elevation spots must be converted to angular units before being applied to the computer.

8C2. SPOTTING METHODS AND TECHNIQUES

There are three methods of visual spotting:

1. The direct method.
2. The bracket-and-halving method.
3. The ladder method.

The method used depends on the type of battery firing, type of target, visibility and range.

8C3. DIRECT METHOD

Spotting by the direct method is, as its name implies, the spotting of salvos (splashes) direct to the target. This is the most desirable procedure, but its use is limited to shorter ranges and good visibility conditions. For reasonably accurate visual spotting at a range of 15,000 yards, a spotting height of 120 feet is required. The splash must be relatively close to the target, and the rangekeeper set-up fairly accurate.

A thoughtful analysis of the problem with reference to the spotting diagram in figure 8B2 reveals that the greatest limitation of the direct method in visual spotting is in range. Deflection spots can be made with equal accuracy at any visible distance. If, then, air observation is available, and the plane spots in range with the ship spotting in deflection, the direct method can be used by the battery at any range at which a portion of the splash is visible to the shipboard spotter. Air spotters cannot spot accurately in deflection unless they have a line of sight containing the firing ship and the target.

Spotting the fall of shot at very short ranges differs from other spotting problems in that range errors are not difficult to judge. However, in determining deflection errors at short ranges, consideration must be given to the travel of the target and the spotter's position relative to the line of projectile flight. For example, with the firing ship and target on opposite courses, target to starboard, a shot fired with correct deflection but long in range will appear to the spotter to be in error to the left of the target. Special short-range splash diagrams aid the spotter in this type of firing.

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8C4. BRACKET-AND-HALVING METHOD

Bracket-and-halving is used at long ranges when no air or radar spot is available. At great distances it is impossible to tell if a splash is short of or over a target, unless the two are in line. If the splash and target are not in line, the first spot is made in deflection only. When target and splashes are in line in deflection, a range spot is made in such a direction and amount as to "cross" the target definitely. The direction of the next spot is reversed, and the size of the spot is cut in half. This "halving" is continued until a straddle is obtained, at which time it may be appropriate to shift to rapid partial salvo or to rapid continuous fire. The spot should not be reduced below pattern size.

8C5. THE LADDER METHOD

When ranging is difficult and visibility poor because of fog, smoke, or darkness, the ladder technique is valuable. Ladders are not particularly adaptable to fast-moving targets. There are many variations of this technique, but the basic procedure is:

1. Fire is deliberately opened short.
2. Succeeding salvos are fired to approach the target in steps not less than pattern size.
3. As soon as the target is crossed, the steps are reversed and halved until the target has again been crossed.

After the target is straddled, a rocking ladder may be used with slow timed fire, or with rapid partial salvo or continuous fire. In a rocking ladder the pattern is shifted back and forth across the target by small arbitrary successive spots, such as +100, 0, -100, . . . introduced at the computer. Its effect is to increase the pattern size, which may be valuable when firing against a target capable of rapid maneuvering. The rocking ladder can be used in conjunction with air or radar spotting, so long as the spotter is kept informed that this technique is being used.

8C6. SPOT PYRAMIDING

SPOT-PYRAMIDING is the application of a new spot before the effect of a previous spot has had time to become apparent. It can occur only in rapid fire, when the interval between shots or salvos is less than the time of flight plus the spotting interval. In that case, when a salvo lands there are one or more other salvos in the air. Suppose the spotter makes a spot on the salvo which has just landed. This spot is applied and a new salvo is fired. Then one or more of the salvos which were already in the air lands, and the spotter, forgetting that his previous spot has not had time to show its effect, spots again. This spot is applied to the next salvo fired, with the result that this salvo is overcorrected and will probably miss, as will subsequent salvos until the spotter sees his mistake and spots back again.

The time of flight clock signal helps to avoid pyramiding. A button on a mechanical time clock is pressed in the plotting room when the salvo on which a spot is applied is fired. The clock has been preset to ring just before the time of flight of the projectile ends. Before the salvo lands, the mechanism sounds a buzzer. This information is then relayed to the spotter via sound-powered phones.

Because spot pyramiding is common and has a disastrous effect on accurate control of fire, the means used to prevent it must be carefully and correctly operated. For example, if the time-of-flight mechanism operator forgets to press the button for a spotted salvo, and the spotter waits for the signal, he may continue to wait after it becomes apparent that his previous spot was incorrect.

When modern fire control systems are being used to solve the fire control problem, the process described in chapter 5 as rate control is used to make constant corrections to the solution. If spots are applied at the same time as rate control corrections, the effect is the same as pyramiding of spots. Under normal circumstances, AA fire is rate controlled. Hence spotting of air bursts is rare.

8C7. SPOTTING WITH RADAR

Radar spotting has proved to be both accurate and reliable within the range of surface batteries. Radar provides a means of spotting which is independent of conditions of visibility, so that blind spotting is possible with blind firing.

Shell splashes appear on the scope as fluctuating echoes which last for several seconds, depending on the size of the projectile and the range. The large column of water thrown up by the projectile produces the echo. Salvos produce larger or multiple echoes on the scope.

If the projectile stays within the vertical limits of the radar beam, its flight to the point of impact can be followed on the scope on main

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sweep. The projectile produces a small, weak, moving echo which begins at the edge of the scope and moves out in range toward the target. At the point of impact the echo stops and grows larger as the splash builds up. Echoes from direct hits or near misses will be lost in the target echo, while salvos which straddle the target may envelope the target echo in the midst of the splash echoes on the scope, thereby making it impossible to distinguish individual splashes. Range errors can usually be estimated by radar with greater accuracy than by optical spotting, but deflection spotting with radar is difficult, especially when the error is small. Near misses sometimes merge with and are indistinguishable from the target pip. Consequently, repeated salvos can land with a 2-mil to 5-mil error which is not separately distinguishable but may not be hits. Target practice is used to determine the minimum deflection error that can be detected on a particular radar. When radar is the only means available for deflection spotting, deflection "rocking ladder" should be used. The order of preference in spotting surface fire is usually: RANGE—radar, air, and visual; DEFLECTION—visual, radar, and air.

In night action, or action under reduced visibility, radar normally spots for both range and deflection.

D. Shore Bombardment and Naval Gunfire Support: Fundamentals

8D1. HISTORICAL INTRODUCTION

In World War II, naval task forces frequently carried out bombardments of enemy installations on shore. After the ineffective results noted during the Tarawa operation in November 1943, shore bombardment techniques were gradually improved and refined through successive landings at Roi-Namur, Eniwetok, Saipan, Guam, Peleliu, the Philippines, Iwo Jima, and Okinawa. Later, the Korean war gave frequent opportunity for the application of the techniques learned in World War II—in particular, the use of naval gunfire to support the landing of troops on defended enemy territory.

Opposed amphibious landing is one of the most hazardous types of military operation. Until World War II, many military authorities believed that such an operation was too hazardous to be attempted. In part, this belief was based on the Allied failure in the amphibious Dardanelles (Gallipoli) campaign during World War I. Analysts ascribe the failure at least partially to inadequate naval preparation before the campaign.

To be successful, naval gunfire support for amphibious operations must be carefully planned in advance, and must be executed with skill and dispatch. It is vitally important in the period after the troops have landed but before adequate artillery can be brought into action. Its full exploitation can be achieved only if ground, naval, and air personnel understand the organization, basic techniques, capabilities, and limitations of naval gunfire support, and follow the standard procedure which has been agreed upon by the joint services.

8D2. PURPOSE OF SHORE BOMBARDMENT AND NAVAL GUNFIRE SUPPORT

Naval gunfire is delivered from ships' batteries not only in support of troop operations, but also to support related naval and air operations, such as mine warfare activities, air-sea rescue operations, reconnaissance and demolition operations, demonstrations, feints, raids, flak suppression during air strikes, and interdiction of coastal roads, railroads, airfields, and troop assembly areas. All these activities rest on the same basic principles as the naval gunfire support of amphibious operations.

The basic task of naval gunfire support units in an amphibious operation is to support the seizure of the objective by destroying or neutralizing:

1. Shore installations that oppose the approach of ships and aircraft to the objective.
2. Defenses that may oppose the landing.
3. Defenses that may oppose the postlanding advance of the troops.

These tasks are carried out in the preparation of the objective for the landing, the support of the landing, and in postlanding support.

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This section takes up the fundamentals of naval gunfire against shore targets, both in support of troop operations and for other purposes.

8D3. TERMINOLOGY: GUNFIRE CLASSIFICATION

Naval gunfire against land targets may be classified in various ways. The classifications are interrelated; terms from several types of classification must be used for a full description. These classifications are based on:

1. Effect sought:

a. DESTRUCTION. Deliberate and accurate fire, usually delivered at short range, for the purpose of destroying a target, usually a material object.

b. NEUTRALIZATION. Rapid, fairly accurate fire delivered for the purpose of hampering, interrupting, or preventing enemy fire, movement, or action. Destruction of weapons and personnel is secondary. The effect of neutralization is comparatively temporary; such fire may have to be repeated.

c. HARASSING FIRE. Sporadic fire delivered during otherwise quiet periods to prevent enemy rest, recuperation, or movement, and in general to lower enemy morale and combat efficiency.

d. INTERDICTION FIRE. Fire designed to prevent or curtail the use by the enemy of an area, bridge, defile, airfield, route of communication, etc.

e. ILLUMINATING FIRE. Gunfire employing illuminating projectiles (star shells) to illuminate the enemy, to detect his movements, to aid our own observation, or to facilitate own troop movements.

2. Tactical use:

a. CLOSE SUPPORTING FIRE. Gunfire delivered on enemy targets which, because of their proximity, present an immediate and serious threat to the supported unit. (Close supporting fire may be as close to friendly troops as 300 yards enfiladed, or 600 yards when the target axis is not parallel to the line of fire.)

b. DEEP SUPPORTING FIRE. Gunfire delivered on objectives not in the immediate vicinity of friendly forces, to neutralize or destroy enemy reserves and weapons, and interfere with enemy command, supply, communications, and observation.

c. PREPARATION FIRE. A heavy volume of prearranged neutralization fire, delivered just prior to a landing or a ground attack by friendly forces on enemy positions.

d. COUNTERBATTERY FIRE. Gunfire delivered against active enemy guns and fire control stations for the purpose of silencing the guns.

e. PREARRANGED OR SCHEDULED FIRE. Gunfire formally planned and executed against targets of known location. Such fire is usually planned well in advance and is executed at a predetermined time.

f. CALL FIRE. Gunfire delivered at the request of troop units ashore, or of some spotting agency. Call-fire missions must not be interrupted without permission of the unit requesting the fire, except in case of emergency.

g. OPPORTUNITY FIRE. Gunfire delivered without formal planning or troop request on newly discovered targets, or upon transitory targets. Targets of opportunity may present themselves to the firing ship at any time, but fire must be delivered only with due regard for safety of friendly troops. Ships delivering fire on targets of opportunity close to own troops require approval of the troop echelon concerned before opening fire. Ships executing deep support missions must assure themselves that the target of opportunity is within their assigned sector of responsibility.

h. RECONNAISSANCE FIRE. Gunfire is delivered in areas where camouflaged positions are suspected or in vital areas where natural cover prevents observation and/or gathering of photo intelligence.

i. FLAK SUPPRESSION FIRE. Gunfire is used to suppress AA fire immediately prior to and during an air attack on enemy positions.

3. Technique of delivery:

a. DIRECT FIRE. Gunfire delivered on a target by using the target itself as a point of aim for laying the guns or director. Direct fire is usually used on targets which can be seen (by optics or radar) from firing ship.

b. INDIRECT FIRE. Gunfire delivered on a target which is not itself used as a point of aim for laying the guns or director. Indirect fire is always used on targets not visible from the ship. This fire is spotted by air spotters or shore fire control party spotters assigned for this specific purpose.

4. Type of fire:

a. AREA FIRE. Gunfire delivered in a prescribed area. Area fire is generally

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neutralization fire.

b. POINT FIRE. Gunfire directed at a definite material target in order to destroy that particular target.

c. DEFILADE FIRE (reverse-slope fire). Gunfire delivered on targets located behind some terrain feature, such as a hill or ridge, which masks the target (fig. 8D1, part B).

d. ENFILADE FIRE. Gunfire delivered on a target in such a manner that the range pattern of the fall of shot coincides with the long axis of the target (fig. 8D1, part A).

8D4. TERMINOLOGY: GENERAL TERMS

Some other general terms used in naval gunfire support operations are:

1. AMPHIBIOUS TASK FORCE. A task organization under naval command composed of assault shipping, embarked troops, and supporting naval units and tactical air units.

2. AMPHIBIOUS TROOPS. Troop elements assigned to an Amphibious Task Force.

3. ADVANCE FORCE. A task organization of ships which conducts operations such as reconnaissance, minesweeping, underwater demolition, diversionary raids, and preliminary bombardment prior to the arrival of the main body of the ATF in the objective area.

4. ATTACK GROUP. A subdivision of an ATF, consisting of assault shipping with embarked troops and supporting naval and tactical air units, operating to establish a landing force on shore and support its operations thereafter. In an operation involving only one Attack Group, it is also the Amphibious Task Force.

5. FIRE SUPPORT UNIT. A group of ships, part of the Attack Group, assigned the mission of naval gunfire support to an amphibious operation.

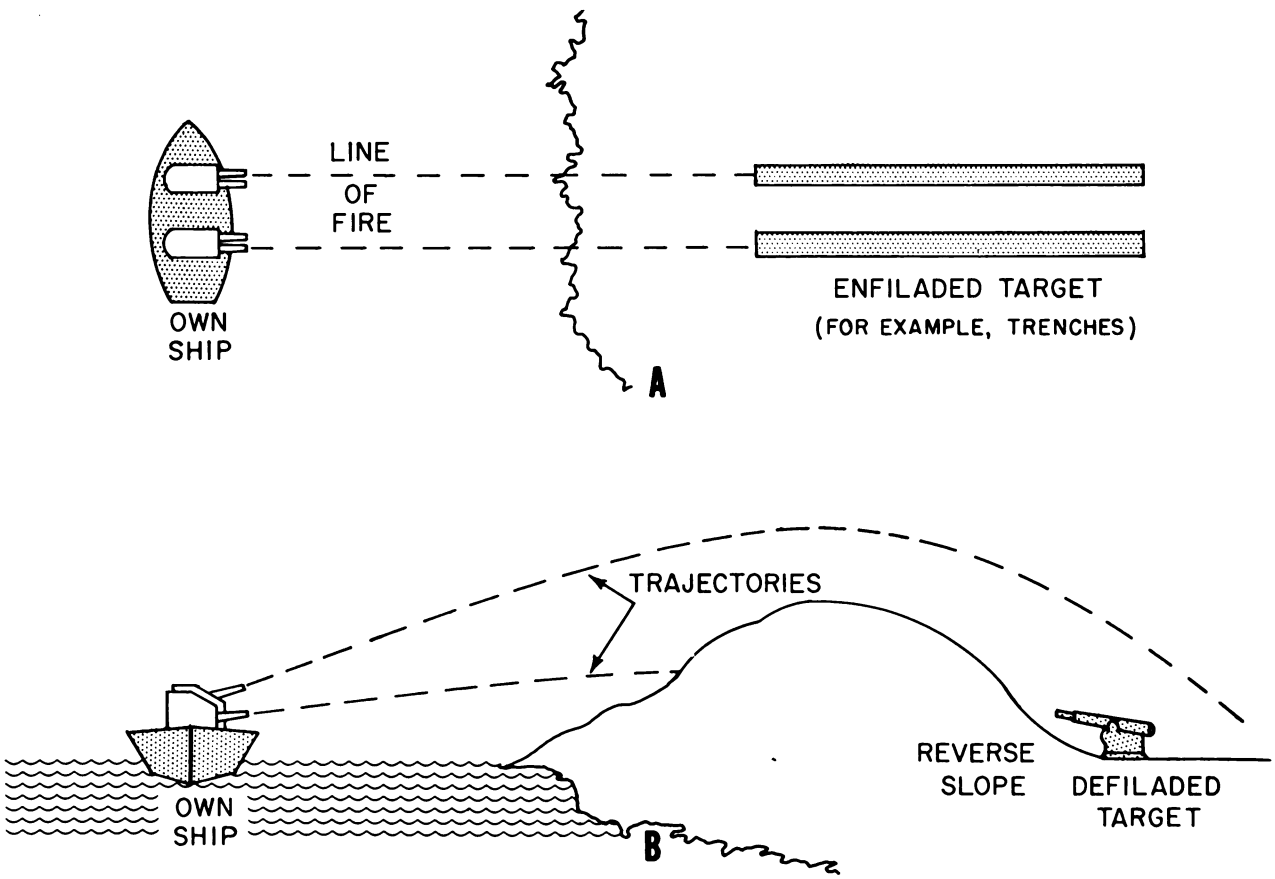

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Figure 8D1. — Types of target.

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6. OBJECTIVE AREA. A defined geographical area within which is located the objective to be captured or reached by the military forces.

7. OBJECTIVE. A physical area or location on the ground, usually a readily identifiable terrain feature, which a troop unit is assigned to capture or occupy. Objectives may be designated as intermediate or final objectives.

8. D-DAY. The day on which an amphibious landing takes place.

9. H-HOUR. The actual time to the minute at which the leading wave of the landing force touches down on the beach; if actual H-hour differs from scheduled H-hour, the actual time of H-hour is broadcast to all ships and troop units by the Amphibious Task Force Commander.

10. ZONE OF RESPONSIBILITY (ZR). The land in the objective area is divided into zones assigned to fire-support units or to individual ships which are responsible for observing, destroying, or neutralizing known enemy installations and for attacking targets of opportunity therein. A ship may fire in its own ZR without clearance from any troop unit. These zones include all land area in the vicinity of the landing forces except the Close Support Area.

11. CLOSE SUPPORT AREA. The area between friendly front lines and the near limits of Zones of Responsibility. Support ships may fire into these areas only upon call from supported troop units, or after receiving clearance from the troop unit concerned to fire on a specific target.

12. PRELIMINARY BOMBARDMENT. Bombardment in the objective area delivered by an Advance Force prior to arrival of the main body of the ATF, with the primary purpose of destroying enemy defenses which might hinder or abort the landing.

E. Shore Bombardment and Naval Gunfire Support: Fire Control

8E1. INTRODUCTION

Naval vessels perform shore bombardment missions either in coordination with troop operations (such as amphibious landings, assaults, or—to a limited degree—offensives) or independently (but in coordination with other naval or air units) for such miscellaneous purposes as interdiction, or destruction of selected targets. This section takes up the fire control aspects of shore bombardment methods and techniques. Section G in this chapter concentrates specifically on shore bombardment operations in preparation for and coordinated with troop operations.

8E2. FIRE CONTROL ASPECTS OF SHORE BOMBARDMENT

So far as fire control is concerned, naval gunfire against stationary land targets presents much the same problem as firing at a ship dead in the water (or, with respect to terrain features at a significant elevation above sea level, at a helicopter hovering at fixed altitude over a specific point). The following special aspects of the problem are worth noting:

1. Ship's Position. The geographical position of the firing ship must be continuously and accurately fixed, as from this are determined the range and bearing of the target in many instances when indirect fire must be used.

2. Current Effects. The set and drift of the current will affect the solution of the fire control problem. When determined, drift may be entered into the computer as target speed; the direction of the set is reversed and introduced as target course.

3. Parallax. Unlike normal gunnery practice at sea, it is often necessary to increase the salvo pattern in deflection in order to cover land targets of large area. One method of doing this is to eliminate horizontal parallax correction by setting horizontal parallax correctors at the gun mounts at infinity (i.e., for a target at infinite range) so that gun bore axes are parallel for any specific range.

4. Terrain. Fire control techniques discussed in chapter 5 took into account only own ship and target and the location and velocity of target with respect to own ship. This is necessary because the featureless seascape and the

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unmarked airspace provide no reference points. On land, however, there are reference points that can be used to assist in laying the guns on target, and in preventing fire on friendly troops, vehicles, and installations. In addition, terrain features complicate correction of the fall of shot. Since solutions assume the point of fall to be in the horizontal plane, the elevation of the target above sea level must be considered in the solution. Figure 8E1 illustrates the errors resulting when the range of a land target is taken from a chart and the target's elevation is not considered. Terrain features also affect the size of the pattern in range; a forward slope decreases it, and a reverse slope increases it. Figure 8E2

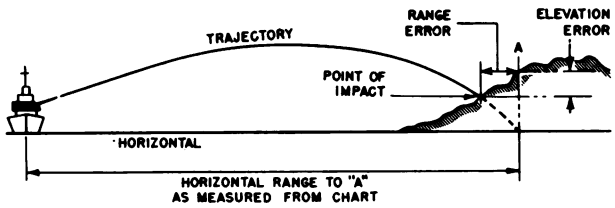

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Figure 8E1.—Errors resulting from failure to compensate for target elevation.

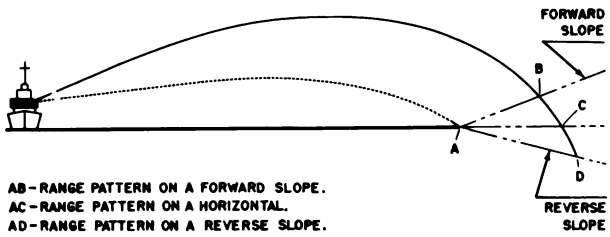

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Figure 8E2.—Effect of terrain slope on the range pattern produced by ship's guns.

illustrates these effects. It is consequently clear that shore bombardment almost always involves the use of maps and charts to an extent rarely required in other types of naval engagements.

8E3. MILITARY GRID REFERENCE SYSTEM

Rapid and accurate means for designating the location of targets are important in shore bombardment. Particularly in naval gunfire support of troop operations, it should be obvious that the troop unit supported and the supporting ship must use a common map. Although they need not be of the same scale, and seldom are, the target maps must be identical regarding terrain features and the method of locating points thereon. Like other techniques of naval gunfire support, the development of a system of target location designations has passed through several stages, following generally a grid-system method. In this method, the land and sea areas at the objective are divided into squares by north-south and east-west lines, which are numbered. These lines are called grid lines.

The Military Grid Reference System imposes vertical and horizontal reference lines over a projection of the earth's surface. Its purpose is to simplify and to increase the accuracy of reporting and plotting in military operations. This grid reference system is based on two projections: the Universal Transverse Mercator (UTM), and the Universal Polar Stereographic (UPS). The UTM is used in the area between 80° south latitude and 80° north latitude; the UPS is used in the polar regions of the earth south and north of these limits. The UTM system divides its area of the earth into a grid pattern with each rectangle in the grid 6° from east to west and 8° from north to south. (Because the grid is rectangular but the earth's surface is not flat, there is some distortion in maps based on the grid, but in any single rectangle this distortion is negligible.) Each rectangle is called a grid zone, and is designated by a letter and a number (e.g., 2P, 5M, etc.). The grid zones are broken down into squares 100,000 meters on a side, and these are further subdivided, with the smallest subdivision a 100-meter square. The subdivisions are systematically identified by letters and numbers, so that in theory any 100-meter square spot on earth can be designated by its number-letter code. This code is called a military grid reference, and it consists of a group of letters and numbers which indicate (1) the grid zone designation, (2) the 100,000-meter square identification, and (3) the grid coordinates; that is, the numerical reference of the point expressed to the desired accuracy. Examples:

52SCU---------- Locating a point within a 100,000-meter square.
52SCU65---------- Locating a point within a 10,000-meter square.
52SCU6957--------- Locating a point within 1,000 meters.
52SCU693578------- Locating a point within 100 meters.

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As a matter of practical referencing in a shore bombardment problem, both the grid zone designation and the 100,000-meter square identification are generally omitted.

The UPS system in similar fashion permits location and identification of any 100-meter square on the earth's surface near the poles.

Fire-support ships are provided with approach charts and bombardment charts for use on their dead-reckoning tracers. (A dead-reckoning tracer or DRT is a mechanical plotting device, usually located in CIC, that will trace own ship track on a chart or plotting paper to any of a range of scales desired, using as inputs own ship course and own ship speed.) These charts are complete in hydrographic as well as topographic detail, and both have a grid system overprinted on them. These charts are of particular use in indirect fire, to be discussed later.

8E4. METHODS OF FIRE AT LAND TARGETS

In conventional gunfire control as described in chapter 5 the target is visible from the ship, either optically or by radar. But this is not always true of land targets; much of the firing any ship performs in shore bombardment will be at targets that nobody on the ship can see through a telescope or a radarscope. Fire at a visible target is called direct fire; fire at an unseen target is indirect fire.

8E5. DIRECT FIRE

Targets visible from the firing ship offer the simplest fire control problem to the ship, and their destruction is easier than targets which require indirect fire. Such targets are: point targets, counterbattery targets, targets of opportunity, or area targets. When the target can be seen, the director can furnish accurate target bearing and elevation. These, with a present range which can be measured, ensure an accurate fire control set-up which should result in early hits. Direct fire is controlled as it would be for fire against enemy ships except that (1) at short ranges better accuracy may be obtained if the gun pointers control gun elevation and firing and (2) when the ship is providing call fire support, the fire will be directed, controlled, and spotted by the shore spotter.

8E6. INDIRECT FIRE: USE OF BOMBARDMENT CHARTS

Indirect fire is employed against targets that cannot be seen by the firing ship.

Given an accurate bombardment chart and knowing the exact position of own ship, it is possible to measure off range and bearing to any land target that has been designated in advance, and to hit that target without using the director or rangefinder.

The ship's position is accurately determined by navigational methods, using positively identified landmarks, and is plotted on the bombardment chart. Since own ship's course and speed are known, future position may be projected ahead along the ship's track by dead reckoning. Again, as in direct fire, because own ship's speed is usually slow, (less than six knots), the set and drift of the currents frequently contribute as much movement to own ship as do the propellers. To generate an accurate solution it is essential to use total movement of own ship. To ascertain own ship's speed, CIC keeps a continuous plot by navigational methods; after several plots have been made, the distance traveled is measured against time and an accurate value of speed is calculated. This speed is set into the computer by hand as target speed, and own ship's speed is set to zero. Target course is then set in manually as the reciprocal of drift or true ship's course.

Future positions are projected ahead along the ship's track on the DRT. A future position is chosen, usually one minute ahead, and from this point bearing and distance to the target are picked off the chart. These values of range and bearing are sent to plot and set into the computer manually. When the ship passes the position chosen, the plotter in CIC gives a "MARK" and the time motor of the computer is turned on. The plotted and computed values of range and bearing are then checked by "MARKING" every 15 or 30 seconds. If the range and bearing agree within reasonable limits (100 yards and 1/2 degree), plot is ready to fire. If not, the check procedure is repeated and the bearing and range in the computer are corrected until the setup is correct. Plot is then ready to shoot after reporting the gun target line (line between firing ship and target) to the shore fire control party.

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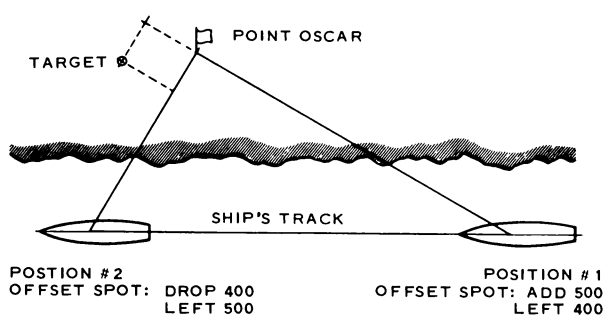
8E7. INDIRECT FIRE: POINT OSCAR METHOD

This method of indirect fire was devised primarily for ships with fire control systems incapable of correctly generating range and bearing to a designated grid point. Its use, however, even by the newest ships is advantageous under certain conditions, such as when no shore spotter or air spotter is available for observing the fall of shot. The method requires a visible point of aim (designated "Point Oscar") near the target, as well as the accurate location of the target and Point Oscar on a map.

In practice, the director line of sight is kept continuously trained and ranged on the point of aim (Point Oscar) to give a continuous range and bearing solution to this point. Salvos are initially fired at Point Oscar as a check on the gun ballistic, and as soon as the mean point of impact has been spotted to hit, range and deflection spots necessary to hit the invisible targets are applied.

Since the motion of the firing ship continuously changes the values of the offsets from the point of aim, frequent changes in these offset spots must be made to ensure hitting the target. This problem is illustrated in figure 8E3. One way to determine correct range and deflection spots continuously is to use a small transparent overlay on which are inscribed 100-yard squares drawn to the same scale as the chart. With the center of the gridded overlay on Point Oscar, and the grid lines oriented to the direction of the line of sight from the ship, range and deflection spots to hit the designated target may be read directly from the grid overlay.



36.31

Figure 8E3. — Point oscar method of indirect fire, showing necessity for continuous changes in offset spots to hit target.

8E8. INDIRECT FIRE: RADAR BEACON

The radar beacon is a portable transmitter-receiver, set up by the shore fire control party, capable of emitting a characteristic signal when keyed by the transmitted pulse of the ship's fire control radar. This signal is different in frequency from the transmitted pulse, to eliminate the normal echo returns from the shore. The signal is received by the fire control radar when the radar receiver has been tuned to receive the beacon frequency. Extremely accurate ranges and bearings to the beacon may be obtained. It can be tracked manually or in automatic radar control.

The radar beacon is used primarily to aid in the delivery of accurate naval gunfire under all conditions of visibility and eliminate the errors of normal navigational plotting, using landmarks and other visual navigational aids.

8E9. INDIRECT FIRE: DEFILADED TARGETS

Targets which are located on the far slope of a hill or ridge between firing ship and target present a particularly difficult problem to the flat trajectory of naval gunfire. The projectile must clear the crest of the hill but fall steeply enough to hit the target beyond. In this situation (defiladed target) an angle of fall must be chosen which is greater than the angle of the reverse slope. Two solutions are then available. The ship may either increase the range or it may use reduced-velocity charges at shorter range to obtain this selected angle of fall. Figure 8E4 illustrates this problem and its solutions. A is the trajectory produced by standard service charges and is too flat; B is the trajectory which can be obtained by using reduced-velocity charges; C is the trajectory which can be obtained with standard service charges by increasing the range.

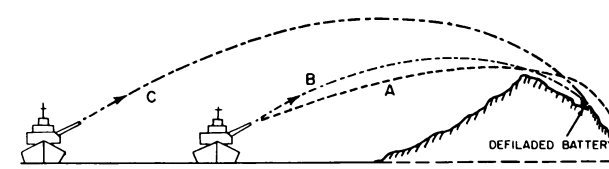


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Figure 8E4. — Problem of hitting a defiladed target.

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If the ship must fire over friendly troops on an elevated position between firing ship and the target, it is necessary to determine target elevation, the elevation of the troop position, and the differences between the two.

8E10. INDIRECT FIRE: FUNCTIONS OF CIC

The primary function of CIC in naval gunfire support is to keep an exact check on the ship's position and from this to determine ranges and bearings to targets designated for indirect fire. Accuracy of fire, when using the method previously described, depends primarily on the skill of the CIC team. CIC also keeps a record of own troop front-line positions, target locations, and other information pertinent to the support of the troops ashore. It acts as the clearing house for information to and from the shore fire control party and air observer, with whom it has direct voice radio communication. In naval gunfire support, CIC keeps the ship's commanding officer, weapon control, and plot advised regarding the requirements for support; furnishes the information necessary to provide the support; and gives the shore fire control party such information as necessary. In addition to target range and bearing, CIC must determine, from contour lines of the bombardment chart, the elevation of the target above sea level and send this to the plotting room so that range error resulting from this elevation may be corrected in the computer.

On cruisers these functions of CIC are often performed in a section of the plotting room. This leaves the ship's CIC free for other duties it must perform.

8E11. SPOTTING IN SHORE BOMBARDMENT

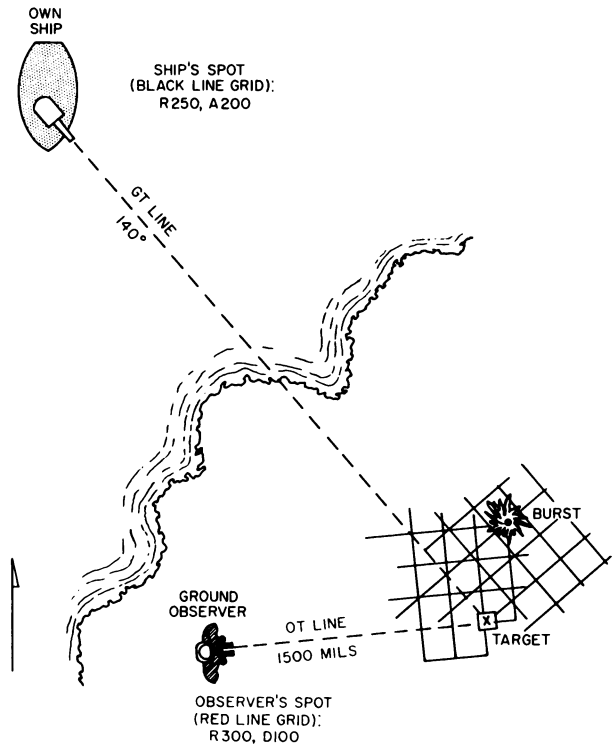
The principles of spotting as discussed earlier in this chapter apply in shore bombardment spotting, but procedures are different when spots are made by a fire control party ashore.

A spotter ashore must be located where he can best observe the fall of shot. Usually this requires him to be as close as possible to the target; this can present him with a very serious frontline problem of survival. He also has an alignment problem. Spots made by an observer aboard the firing ship are naturally oriented to the line between the firing ship and target (GTZ). Spots made from aircraft can be oriented readily to the gun-target line, since both the gun and the target are normally within the aircraft observer's field of vision. But spotters ashore are frequently unable to see the firing ship and, so long as they are required to make their reports in relation to the gun-target line, the value of the information sent by the spotter to the ship is limited.

To simplify this problem for the spotter, the target-grid system for use in spotting the fall of shot on land is used. The target-grid system is part of the standard spotting and general shore bombardment procedure for use within the naval service.

The system permits the observer to spot the fall of shot just as he sees it along his own line of sight to the target (called the observer-target line), irrespective of the position of the firing ship and of the gun-target line. The procedure is briefly outlined as follows (fig. 8E5):

1. The observer, in his call for fire, must give the azimuth from himself to the target; direction OT in the illustration.
2. The observer makes all his observations and corrections with respect to the observer-target line (OT).



59.99

Figure 8E5. — Target-grid spotting problem.

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3. The CIC or plotting room crew converts the corrections of the observer to corrections with respect to the gun-target line (GT).

4. The plotting room crew introduces into the range-keeper (computer) the spots corrected to the gun-target line.

The concrete example which figure 8E5 illustrates is explained in the next article below.

8E12. APPLICATION OF THE TARGET-GRID SYSTEM

As the preceding article stated, the target-grid system permits the ground observer to call his spots with respect to his own line of sight (OT in figure 8E5), while spots introduced into the ship's fire control system are stated with respect to the ship's line of fire. The practical application of the target-grid system depends on quick, accurate conversion from spots in terms of the observer's line of sight (OT) to spots in terms of the line from gun to target (GT). This is done graphically by the grid spot converter, which superimposes a set of coordinates based on OT upon a set based on GT.

The converter (fig. 8E6) consists of a transparent circular plastic disc secured by a pivot at its center to a rectangular white plastic piece. Each is printed with a square grid pattern, with the squares on both pieces of equal size, with the words LEFT and RIGHT on either side and the words ADD and DROP on the upper and lower parts. The grid lines on both pieces are numbered; each square represents an increment of 100 yards.

The grid pattern on the white plastic piece is printed in black and inscribed in a circle graduated counterclockwise in degrees; this represents the reference grid for own ship. On the 0-180° line of this pattern is a black arrow. At the top of the own ship pattern appears an additional degree calibration for introducing magnetic variation correction.

The transparent pivoted disc has its grid pattern printed in red; the circumference of its circle (which is concentric with that of the own ship pattern) is graduated counterclockwise in mils. A red arrow is on the 0-3200 mil line. This is the reference grid for the observer.

The procedure for using the converter is explained below. Figure 8E6 shows the converter set up for the problem illustrated in figure 8E5. Figure 8E5 illustrates in red the part of the grid pattern that relates to the observer's spots; the black grid pattern relates to own ship line of fire. Magnetic variation is assumed to be zero.

The procedure follows:

1. The converter operator obtains the true azimuth of the GT line in degrees by reading the true target bearing from the computer. He makes a mark with a grease pencil at this azimuth on the lower (black) disc. He then obtains the azimuth of the OT line in mils from the observer (spotter) via CIC. He makes another mark at this azimuth on the upper (red) disc.

2. The operator then rotates the upper disc until the two pencil marks match. (In the figure, GT is 140° and OT is 1500 mils.) The red and black arrows now indicate the angular relationship of the observer's line of sight and the ship's line of fire.

3. When a spot is received, the operator starts at the center of the upper disc, which represents the burst, and plots the observer's spot: "Right 300; drop 100", on the observer's reference grid (red), with each square representing 100 yards. The point plotted then represents the target, which is marked with grease pencil.

4. He now goes back to the burst (center) and counts off the squares to the target point as projected onto the lower disc (own ship reference grid). This gives a spot with reference to the ship's line of fire of "Right 250, add 200." This is the spot which is applied to the computer. (R250 is in yards, and must be converted to mils before it can be applied.)

8E13. COMPUTERS USED SPECIFICALLY FOR SHORE BOMBARDMENT

Shore bombardment computers are electronic plotting computers which operate in conjunction with the fire control computers in solving the gunfire support problem. They are primarily an electronic DRT, which continuously solves for ranges and for bearings to the target, eliminating all manual plotting. They are fast and give more accurate results. They are particularly effective when used in conjunction with the radar beacon. Some cruisers and new construction DD's are equipped with these computers.

Shore bombardment computers are primarily an "indirect" fire control device permitting blind firing directly from bombardment charts. Figure 8E7 shows the relationship between the shore bombardment computer and the main

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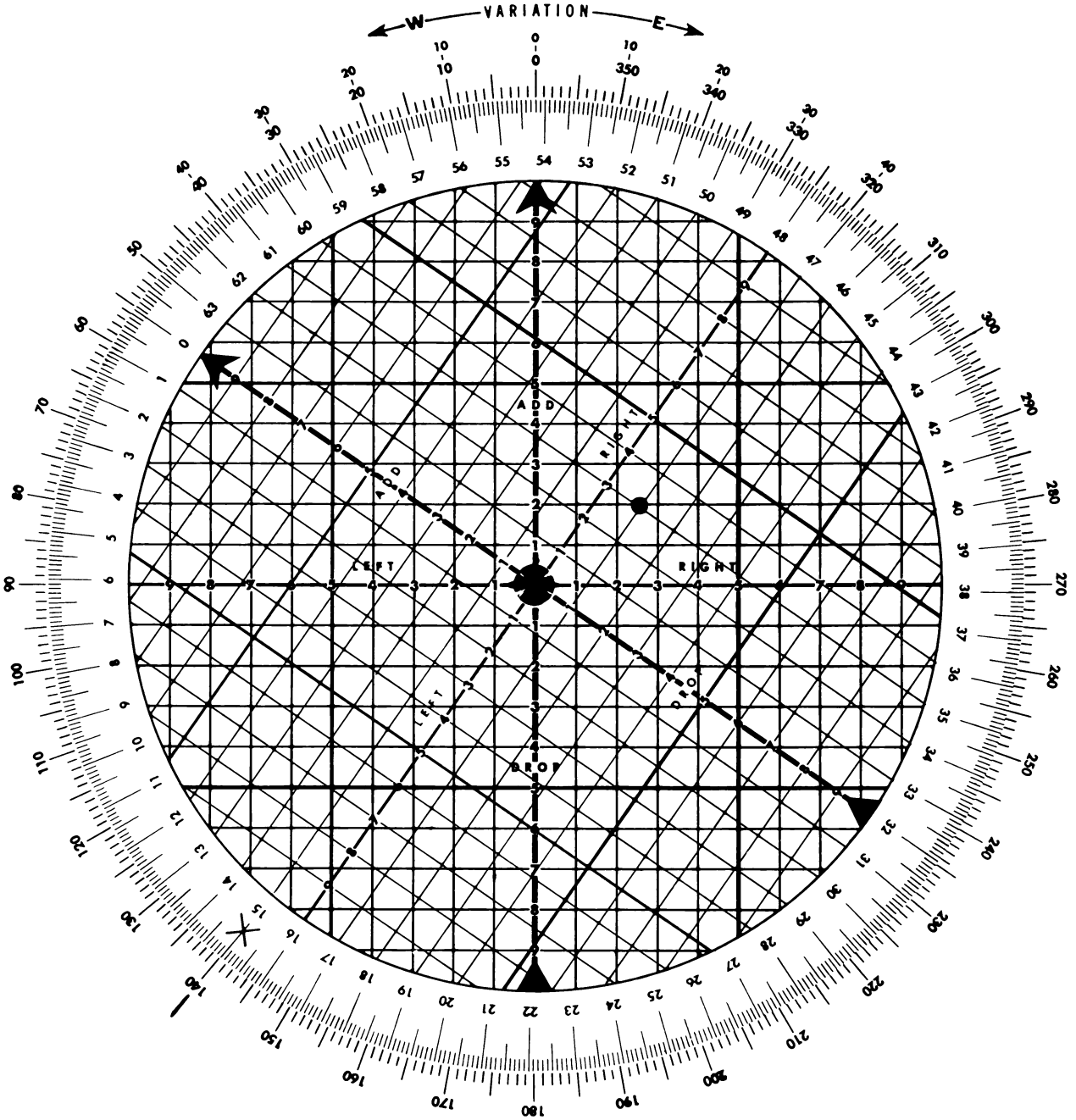

59.100

Figure 8E6. — Grid spot converter.

battery fire control system. The computer provides no ballistic data. It fits into the main battery or 5-inch fire control system between the gun director and the ballistic computer. It receives from the navigating or reference director continuous values of bearing and range to a reference point of aim (either a shore target or a radar beacon). These values establish own-ship position and control the plotting head which continuously indicates ship's track. The tracking head moving underneath a map or the target by means of handcranks automatically

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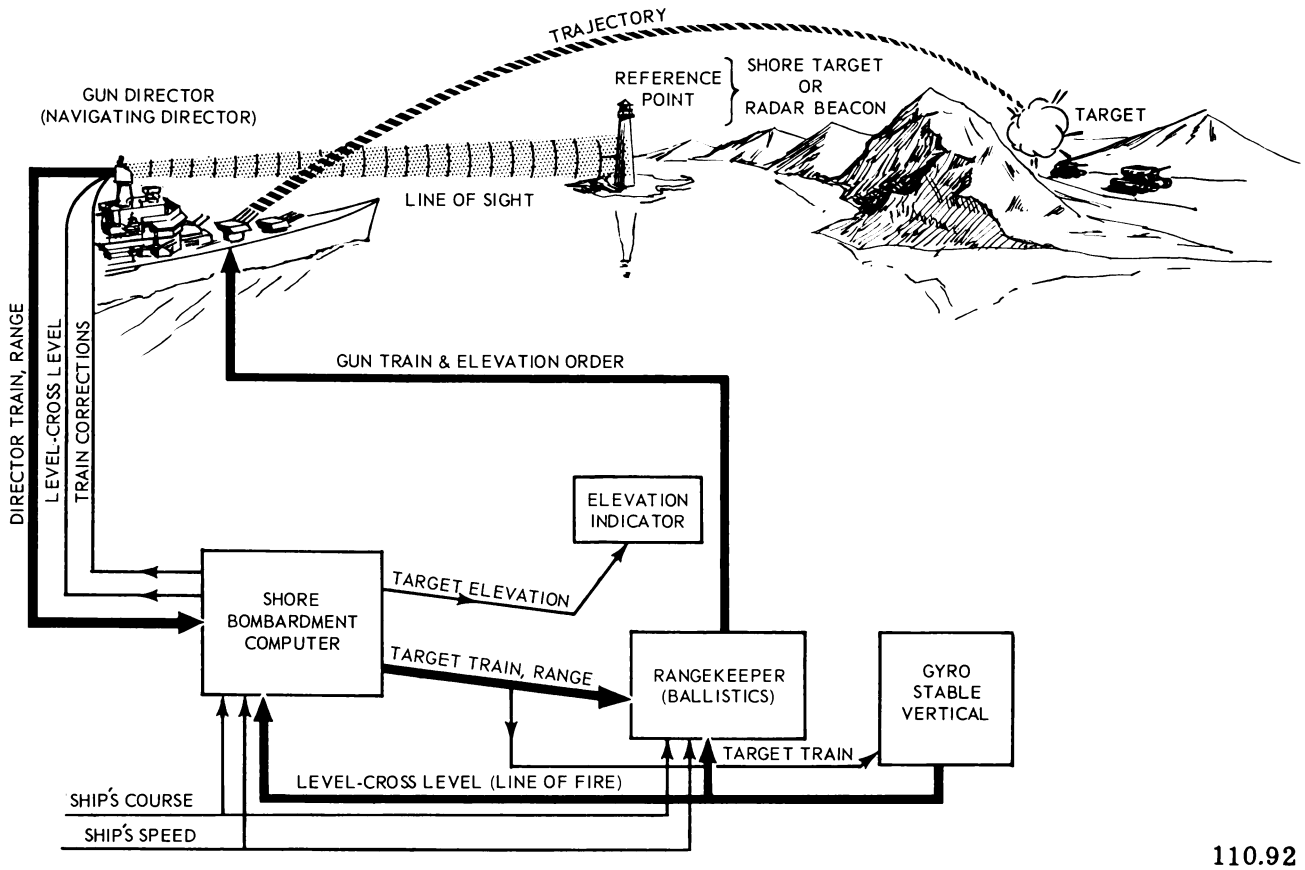

Figure 8E7. — The shore bombardment computer.

inserts the offset between the reference point and target.

The computer then computes the bearing and range to the target. These are transmitted to the ballistic computer, which is operated in the normal manner. The height of the reference point and the target are manually set and used to convert slant range to ground range, and vice versa. Basically, the computer is a triangulation computer which continuously converts bearing and range to a reference point into bearing and range to an offset target.

Since the gun directors train in the deck plane, and thus transmit deck plane bearing information, it is necessary to correct both reference point bearing and target bearing for deck tilt.

The computer also computes stabilization signals of level and crosslevel and an aided tracking signal to the navigating director.

Now let us compare the two methods of firing indirect shore bombardment (CIC giving us navigational data and the shore bombardment computer methods). First, let us consider the time element. In the older CIC method it took longer to get a solution because the information had to be plotted on the DRT, relayed to the fire control plotting room by telephone, then put in the computer by hand. In using the shore bombardment computer, inputs of range and bearing are automatic; hence we have a more accurate first salvo solution in less time. Another factor is that set and drift are no longer required, since the shore bombardment computer will automatically and continuously compute own ship's position.

Greater accuracy is obtained by using the shore bombardment computer because the bombardment chart is laid out on the computer and the inputs are made in north-south/east-west coordinates, and the fire control radar is used to establish a known range and bearing reference instead of using navigational or surface-search radar ranges.

The computer under discussion has been the Mk 48. The Mk 47 computer is similar in shore bombardment capabilities; however, it also can be used advantageously in AAW.

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F. Shore Bombardment and Naval Gunfire Support: Communications

8F1. EXTERNAL COMMUNICATIONS SETUP FOR SHORE BOMBARDMENT

The subject of external communications in shore bombardment is a complex one in which the weapons liaison officer (WLO) plays a major role. It is obvious that this section can do scarcely more than acquaint the student with one corner of this ramified specialty, and even this corner cannot be thoroughly explored here—only surveyed rapidly with attention to a few essentials. Two- or three-day shore bombardment schools are available within the fleet which instruct a ship's "team" in the specifics of shore bombardment communications and procedure.

Figure 8F1 illustrates schematically the communications net (i.e., the participating stations) for a single ship in support of a battalion of troops ashore. The WLO aboard a ship (typically, a battalion would be supported by a destroyer) is located in CIC, where he is connected by battle telephone with plot and the main battery director (the officer usually wears the phones himself) and by radio with the other stations in the net. Most often the radio contact is by voice radio-telephone (R/T) rather than by continuous-wave (CW) code transmission. The officer's voice does not go on the air; he communicates through a radio-telephone operator (not shown in the figure in CIC) who functions as his talker and also logs the spots and other information received as he gets it.

The radiotelephone transmissions are usually frequency-modulated (FM) in the very-high-frequency (VHF) band (e.g., 20 to 60 megacycles) or ultra-high-frequency (UHF) band (e.g., 200 to 300 megacycles), though other bands may be used. The shore fire control party uses a portable battery-powered transceiver which can be carried on the back of one man. With a low power output, which is all that is possible in such equipment, the range is only a few miles, but this is all that is necessary.

The air spotter is usually in a relatively low-speed spotting fixed-wing aircraft (often a light civilian-type one- or two-place plane) or in a helicopter. The spotter and his shore fire control party are in a forward position where they can observe the target area. The naval gunfire liaison officer is usually in a location farther from the target area.

Most of the communication takes place between the spotters and the ship. The naval gunfire liaison officer sets up the net but in general does not participate directly in its functioning unless components in the net are changed, or unless it is necessary to control it for other reasons.

In general, so far as shipboard communication operations in shore bombardment are concerned, if communications are carried on through CIC, CIC follows these procedures:

1. Locates on the chart the target assigned by the shore fire control party.
2. Furnishes bearing, range, and elevation to control and plot.
3. Checks the computed solution with CIC's plotted solution.
4. Relays spots received from the shore fire control party to control and plot.
5. Plots forward lines continuously and accurately.

8F2. SPECIMEN OF SPOTTING COMMUNICATIONS OPERATION

To illustrate by example an instance of the use of external communications in shore bombardment, there is reproduced below a specimen of the voice communication between shore spotter and ship in a simple spotting operation.

The ship's code name is RIFLE; the spotter's code name is EYEPIECE. The communications setup resembles that in figure 8F1 except that there is no air spotter and the naval gunfire liaison officer does not participate in the proceedings quoted in the following table:

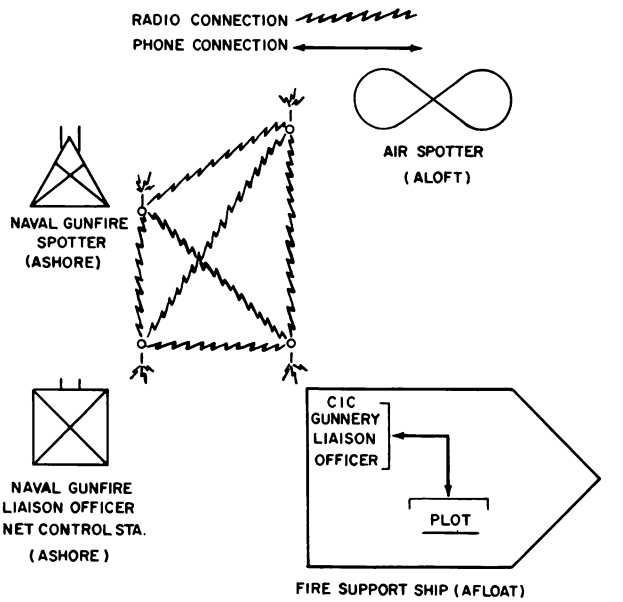

Figure 8F1. — Shore fire control spotting net. Schematic. 110.93

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From	Nature of action	Radio telephony	Remarks
Ground spotter.	Call for fire.	RIFLE this is EYEPIECE-Break-target number nine five zero-bearing one five hundred mils-grid coordinates six nine three five seven eight-height seven five meters-one hundred troops in open-danger close northwest three hundred-two guns main armament-high explosive-fuze quick-will adjust -break-over.	a. Target numbers are selected from appropriate instructions contained in operation order. b. The spotting line may be expressed in mils or degrees, from grid, magnetic, or true north. c. The height of the target is always included. It may be given either in yards or meters, but if unspecified will be in feet. d. The target description should be brief yet clear enough to permit evaluation by the firing ship and for target intelligence. e. Proximity of friendly troops to target is sent so that the ship can provide for safe firing of the opening salvo.
Ship - - -	Repetition back.	Target number nine five zero -bearing - - - - - - etc. -out.	
Ship - - -	Ready report.	First salvo at southeast four hundred-ready-over.	Expected position of fall of shot of initial salvo always given when call fire includes a danger element.
Spotter -	Fire Command	First salvo at southeast four hundred-ready-fire-over.	
Ship - - -	Repetition back.	Fire-out.	
Ship - - -	Fire report.	Shot . . . standby-out----	"Shot" is made on firing. "Standby" is made 5 seconds before round is due to fall.
Spotter -	Calls the spot.	Right three hundred-drop one hundred-over	Figure 8E5 illustrates this spot.
Ship - - -	Repetition	Right three hundred-drop one hundred-out.	
Ship - - -		Shot . . . standby-out.	
Spotter -		Drop one hundred-over.	
Ship - - -	Repetition back.	Drop one hundred-out.	

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From	Nature of action	Radio telephony	Remarks
Ship - - -		Shot . . . standby–out.	
Spotter -		Left five zero repeat–six guns four salvos–fire for effect–over.	Spotter has enclosed target in a 100-yard bracket. He halves the bracket, and goes to fire for effect.
Ship - - -	Repetition back.	Left five zero repeat–six guns four salvos–fire for effect–out.	
Ship - - -		Shot . . . standby–out--------	Made for first salvo only of fire for effect group.
Ship - - -		Rounds complete–over---------	All fire for effect salvos have been fired.
Spotter -		Rounds complete–out.	
Spotter -		Spreading fire–left one hundred –add three hundred six guns four salvos–fire for effect–over.	Spotter wishes to distribute fire over the target area.
Ship - - -	Repetition back.	Spreading fire–left . . . etc. –out.	
Ship - - -		Shot . . . rounds complete . . . standby–out.	Second fire for effect salvo was fired before the first salvo was due to burst.
Spotter -		End of target–fire effective–over----------	Spotter is satisfied that target is neutralized. No further fire is required.
Ship - - -	Repetition back.	End of target . . . etc. –out.	

G. Shore Bombardment and Naval Gunfire Support: Operations

8G1. ADVANTAGES OF NAVAL GUNFIRE SUPPORT FOR TROOP OPERATIONS

Naval gunfire has many capabilities, advantageous for troop support in landings, which conventional land artillery does not possess. These include:

1. AVAILABILITY. Gunfire support ships are continuously available before, during, and after the landing, as long as the zone of action ashore is within the range of the ship's guns.

2. MOBILITY. Within the limitations of navigation, ships can move rapidly from one area to another as the situation ashore develops. At the same time, the most favorable ranges and lines of fire can be fully exploited, and enemy counterfire can be evaded.

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3. HIGH RATE OF FIRE. Power loading and mechanical ammunition supply makes it possible to deliver a large volume of fire in a short time. This characteristic is of great value in neutralization missions, where it is necessary to saturate the target area with a large volume of fire.

4. HIGH MUZZLE VELOCITY AND FLAT TRAJECTORY. Naval guns, particularly those of heavy caliber, have great penetration and destructive power, especially against installations presenting vertical surfaces.

5. SMALL DEFLECTION PATTERN. The comparatively small dispersion in deflection of naval guns makes them valuable for close support of troops when the line of fire can be made parallel to the troops' front line (enfilade fire) (fig. 8D1, part A).

8G2. LIMITATIONS OF NAVAL GUNFIRE SUPPORT FOR TROOP OPERATIONS

Tactical employment of naval gunfire in support of troops also has certain limitations, which must be considered in both planning and operational stages. The most important are:

1. Necessity for observation. Naval gunfire, except for area fire on very large targets, must be observed and corrected to be effective. This requires a spotting agency, such as a ground, air, or shipboard spotter.

2. Navigational limitations. Ships are forced to remain in safe, navigable, mine-free waters, and therefore sometimes cannot take advantage of the positions most favorable for the attack of targets. In some cases, ships cannot fire at all on certain defiladed (located on a reverse slope) targets (fig. 8D1, part B). Obviously, the maximum range inland is limited by the position of the ships, as well as by the characteristics of the weapons used. Further, the fact that the ship is in motion requires the continuous and accurate fixing of the ship's position for delivery of fire on targets not visible from the ship.

3. Communications limitations. Radio and visual communications between ship and shore are not as flexible, reliable, or secure as communications by wire or telephone.

4. Limitations of pattern. By comparison with artillery, naval guns have a small deflection pattern, a large range pattern, and a flat trajectory. This is an advantage in some respects, but requires careful selection of lines of fire when engaging targets near our own troops. The difficulty of fire against defiladed targets may be overcome by using reduced-velocity charges or by increasing the range to obtain a greater angle of fall.

5. Limited ammunition capacity. The limited capacity of the ship's magazines, coupled with the fact that a ship must always retain a certain amount of ammunition for its own protection, restricts the ability of any one ship to maintain uninterrupted support over an extended period of time. This disadvantage may be overcome by providing adequate ammunition replenishment and by rotating ships assigned to support missions.

8G3. SELECTION OF WEAPONS

Selection of the guns or weapons to be used in naval gunfire support is determined by the nature and size of the target to be engaged, and by the proximity of friendly troops to the target. The 5-inch gun is normally used for close supporting fire; its rapid rate of fire and relatively small pattern size make it an excellent weapon for neutralization and destruction of targets immediately in front of advancing troops. Destroyers are usually assigned close supporting-fire duties because their maneuverability permits them to shift positions easily and quickly and to take positions close inshore for direct fire on targets in coastal areas.

Eight-inch guns, with their great accuracy at long range, are normally reserved for deep supporting fire. The lethal bursting radii of projectiles from these guns limit their employment in close support. Moreover, ships mounting these guns (cruisers) are hampered in responding quickly to fire commands because they are less maneuverable than destroyers, and their fire control organization is more complex. The larger ships also have additional duties. Destructive power of large-caliber projectiles makes them particularly effective against heavy installations ashore.

Six-inch guns are suitable for either close or deep support, but the light cruisers mounting these guns are better adapted for deep support use, since their maneuverability is restricted.

Three-inch and 5-inch guns of DE's and APD's, are suitable for harassing fire missions of the sort often executed against areas remote from our own troops, such as towns, harbors, and coastal air strips. The use of these ships for this purpose provides a necessary feature of support, and releases ships with more accurate fire control equipment for use where precision fire is required.

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Three-inch guns are effective for area neutralization where heavier guns are not required. The guns are particularly effective against shore-line targets, especially enemy personnel in caves. When such fire is controlled by the dual-purpose gun directors, it is accurate and effective at short ranges; when not so controlled, larger safety margins with respect to own troops must be allowed.

8G4. SELECTION OF PROJECTILES AND FUZES

Selection of the projectile type to be used in support of troops depends upon the type of target and the effect sought on that target. Because in shore bombardment a battery is likely to be shifted frequently and rapidly from one target to another (quite likely of different type, requiring a change in ammunition), ammunition-handling personnel should be prepared to change projectiles and fuzes on very little notice.

High-capacity (HC) projectiles are especially for use in shore bombardment. They have great explosive content (at the expense of penetrative ability) and produce a heavy blasting and fragmentation effect. HC is therefore suitable for neutralization or for destruction of relatively light installations.

Antiaircraft common (AAC) projectiles are similar to HC projectiles in explosive and penetrative qualities. Their effective bursting radius of 35 to 50 yards fits them for close-support neutralization fire.

Armor-piercing (AP) and common (COM) projectiles are designed to penetrate armor plate before detonating. Their use in shore bombardment is limited to fire on fixed enemy defenses, such as concrete pillboxes and blockhouses which cannot be reduced by HC projectiles.

White-phosphorus (WP) projectiles have been found very useful for screening, incendiary, and antipersonnel effect. They may also be used as "identifying or marker shot" to identify salvos, to permit spotting when the impact burst is invisible due to foliage, or to give a prearranged signal to the troops supported.

Illuminating (ILLUM) projectiles are used to provide illumination only.

Fuzes used with HC, AAC, and WP projectiles may be selected to meet different objectives. Mechanical time fuzes may be used to provide air bursts for maximum effect against personnel and light equipment. They should be set to burst 25 to 50 feet directly above the target. Proximity fuzes, which require no advance setting, accomplish the same purpose with greater accuracy and less difficult fire control, as they compensate automatically for variations in ground elevation. Point-detonating fuzes also require no advance setting but produce a lower and more concentrated burst, often desirable for demolition. Base-detonating fuzes are, of course, required against armored or other heavy structures.

8G5. TARGET INTELLIGENCE

Before undertaking any bombardment of land targets, a thorough familiarity with the terrain and hydrographic features of the objective, and with the location of profitable targets, must be acquired. The study of available charts, maps, aerial photographs, radar PPI simulations, mosaics, and other pertinent information will be necessary for rapid, effective troop support. Normally these charts, maps, photographs, and target information will be furnished each fire-support ship prior to the operation. The systematic destruction of defenses requires the continuous assembly and evaluation of targets known beforehand, and of those discovered in the course of the operation. Damage assessment must be based upon visual observation and photo-analysis. A common error is over-optimism as to the effectiveness of naval fire against land targets.

8G6. PHASES OF NAVAL GUNFIRE—SUPPORT OPERATIONS

It is convenient to divide naval gunfire support for a landing operation into three general phases as follows:

1. PRELANDING BOMBARDMENT. This phase, which may commence well in advance of D-day, utilizes quick raids by surface ships to inflict damage and cause confusion, after which the ships retire. Similar strikes may be carried out by aircraft during this phase.

More often the bombardment group will move into position a few days prior to D-day and commence its schedule of prearranged fire which may continue right up to H-hour (the time of landing of the first wave of troops) or may be interrupted by retirement of the bombardment group for reasons of safety.

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During this period, the effect sought by the bombardment is destruction of beach defenses, gun control and observation posts, or any defenses which could effectively oppose the landing. Slow, deliberate, close-range destructive fire is used whenever possible. In this and later phases the identity of the actual landing beaches may be concealed by a schedule of fire covering other areas. The number of ships engaged in the prelanding bombardment, its duration, and the type of ammunition expended will depend upon such factors as the number of ships and planes available, logistics (especially ammunition supply), and the nature of the terrain and its defenses.

In addition to its primary purpose of destroying designated targets which may hamper the landing, the force may provide cover for minesweepers, underwater demolition teams, and oceanographic survey vessels. During the night it may engage in harassing fire. During the last hours prior to H-hour it may be called upon for interdiction fire to prevent assembly of reinforcements and their movement into the area of the beaches to man or repair equipment. On D-day, before troops embark, bombardment of strong resistance points is intensified.

The force may also cover final minesweeping operations and the approach of the attack force, especially the transports. When transports are in position off the landing beaches, fire can be concentrated on strong points which intelligence reports or observation indicate have not been destroyed.

During this period air strikes are often scheduled to bomb and strafe the beaches. Provisions must be made to control fire so as to avoid hitting friendly planes.

2. SUPPORT DURING THE LANDING. The primary missions of naval gunfire in this phase are to protect the transports while the landing force is embarking in boats, to silence batteries which might destroy the assault waves as the boats move in to the beach, and to cover the actual landing of troops. The barrage must be lifted inland or shifted to the flanks as the troops near the beach to avoid hitting the landing force as well as to neutralize strong points from which destructive crossfire could pour on the beaches. In addition to close supporting neutralization fire on the landing and adjacent areas, deep supporting fire must concurrently prevent enemy troop movement toward the landing area and neutralize more remote opposing enemy defenses.

During the last few minutes, as the first wave nears the beach, a final air strike often parallels the beach, strafing and driving the enemy to cover.

Because things happen so fast, and because communications with the troops being supported are rarely adequate in the critical period during and immediately following a landing, most of the supporting fire must be planned in advance, for delivery according to a carefully formulated and coordinated time schedule.

3. POSTLANDING AND TROOP ADVANCE PHASE. Naval gunfire is employed after the landing phase to assist the advance of troops to their final objectives. The postlanding fire schedule must be carefully planned for coordination with the estimated troop advance, but must be capable of quick modification to permit repeating, extending, or discontinuing any portion of the schedule when the advance differs from the plan. Close and deep supporting fire must be scheduled to continue after the landing, to neutralize enemy opposition which would hinder the rapid establishment of organized troops ashore. Scheduled fire after H-hour must last well beyond the estimated time required to establish effective naval gunfire control agencies ashore. With heavily defended objectives, scheduled fire for close support must continue at least an hour after the landing, and for deep support at least 4 hours.

Close supporting fire from ships assigned to them, daily or upon special request, is made continuously available to troop units in assault. Deep support, including daily destructive fire missions, preparation fire for troop attacks, and night harassing fire, are scheduled for daily execution in fulfillment of troop requests. This phase of naval gunfire support begins upon completion of the prearranged scheduled fire in support of the landing, and continues until naval gunfire is no longer required for support.

8G7. PREFERRED PRACTICES IN NAVAL GUNFIRE SUPPORT

Effective support of troops by naval gunfire depends on certain operating principles and techniques of delivery—what might be called tricks of the trade, or recommended operating practice. This article briefly discusses a number of these principles and recommended techniques.

1. PREREQUISITES TO EFFECTIVE SUPPORT FIRE. Prerequisite to effective support

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are proper alignment of the fire control system and gun battery, rapid and reliable internal and external communications, and well-trained ship control, fire control, and gun control personnel.

For optimum effectiveness, personnel aboard a firing ship should be thoroughly familiar with the land areas the ship is assigned to cover. This can be achieved through repeated firing, observation, and analysis. Consequently, it is best to avoid shifting ships to different areas of responsibility once their personnel have become acquainted with the areas originally assigned.

2. COUNTERBATTERY FIRE. The first duty of naval gunfire in all phases of support is immediate and effective silencing of heavy enemy weapons which open fire on our forces. Hence a counterbattery plan anticipating all contingencies must be in constant readiness, and fire-support ships must be ready and alert at all times for the delivery of this fire. If the source of enemy fire is not known, heavy counterbattery fire on suspected sources is delivered until the enemy battery is located. The whereabouts of friendly forces must be kept in mind during such an attack.

3. STEAMING SPEED. Unlike surface or air action at sea, naval gunfire support requires moderately low speeds. High speed in a firing ship requires it to make frequent course reversals to remain in its assigned sector, causes inaccuracies in establishing ship's position for indirect fire, takes the ship too quickly beyond effective firing positions, and may result in interference with other activities offshore. The best practice is to select a low speed which will allow good control of the ship and the supporting fire, consistent with the tactical situation and the submarine menace. If necessary, the ship may lie to or anchor, maintaining desired heading by the use of the engines. Best results for indirect fire will be obtained if ships steam on a steady course at a constant low speed.

4. NEUTRALIZATION. Volume of fire required for neutralization of a target area is difficult to establish. The standard volume established before World War II prescribed the equivalent of sixteen 75-mm projectiles per minute per 100-yard square as being sufficient for neutralization. Although the experiences of World War II showed this often to be entirely inadequate, it is still a valuable guide which may be modified as conditions dictate. Experience proved that the blast effect of bursting projectiles had been highly overrated in neutralizing effect; it was found instead that neutralization primarily depended upon the casualties produced or threatened by flying fragments. Fragmentation effects vary greatly, even in identical projectiles, because they depend on such factors as angle of fall and terminal velocity. For example, the number of casualties may double with an increase in angle of fall from 10° to 60°. Effectiveness of fire for neutralization will also vary with terrain, types of enemy installations, and quality of the enemy troops.

5. USE OF ILLUMINATING PROJECTILES (star shells). Illumination of land areas by naval star shells is effective in preventing enemy counterattacks, infiltration, and the movement of enemy troops at night. Its morale-boosting effect on our own troops generally results in requests for exorbitant star-shell expenditures to produce unnecessary illumination of the land area throughout the night. Except during actual enemy counterattacks, star shells fired at a reduced rate and at irregular intervals normally discourage enemy movement. Maximum benefit from the limited supply of star shells available requires judicious control and coordination by troop units to avoid silhouetting of own forces ashore and afloat. When delivering illumination fire, the line of fire must be so adjusted with relation to our front lines that friendly troops are not endangered by star-shell bodies. Searchlight illumination for troop support is generally unsuccessful; it almost invariably draws enemy fire on the ship employing it.

6. RECOMMENDED PRACTICES IN FIRING. Use direct fire whenever possible. Indirect fire requires more ammunition and time than direct fire for equal destructive success. Indirect fire requires air or ground observation of the fall of shot in order to ensure hits on point targets; this is not essential for direct fire. The effectiveness of naval gunfire is increased by the employment of an air spotter working with a ground spotter.

Once established, maintenance of the hitting gun range and deflection is essential to effective destructive fire. Periods of continuous slow fire with reduced salvos are therefore preferable to more rapid fire interspersed with relatively long nonfiring intervals.

For decisive destruction of heavy defenses, use, if at all possible, very close-range, slow, deliberate, direct fire. Fire-support ships should usually operate as close inshore as safe navigation, the tactical situation, enemy shore batteries, and the type of fire required will permit.

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When close supporting neutralization fire on the landing area in support of troops about to land is scheduled to be shifted on a time basis relative to the estimated time of H-hour, it must be adjusted according to the actual position of the troop landing craft. From reports of landing-craft progress received, but primarily from own observation when possible, fire-support ships must individually determine when their fire is about to endanger troops nearing shore, and accordingly shift the fire from the landing area.

Close cooperation between ships and the troop units assigned for support is essential for information between supporting ships and troop units can ensure intelligent and effective fire support. Of particular importance is the safety requirement that all fire-support ships maintain an up-to-date plot of own troop front-line positions as periodically announced by landing force elements. This not only prevents endangering own troops, but permits selection of the most suitable line of fire with respect to troop lines, and safeguards friendly aircraft operating in the area.

Specific information on all phases of gunfire support in amphibious operations may be found in NWIP 22-2.

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CHAPTER 9

ROCKETS AND BOMBS

A. Rockets and the Rocket Principle

9A1. GENERAL

A rocket is a missile propelled by reaction thrust produced by the escape of gases evolved from the burning of solid, liquid, or gaseous propellants completely contained within itself. A true rocket by definition does not, for example, use atmospheric oxygen to burn its fuel.

In general usage, any missile that is rocket propelled can properly be called a rocket. In naval ordnance terminology, however, the unqualified term "rocket" denotes a rocket-propelled missile that is not guided after launching, either by built-in equipment or by command signals from without. As used in this chapter, the term "rocket" means only this. Rocket-propelled missiles that are guided after launching are guided missiles, and are covered in Principles of Guided Missiles and Nuclear Weapons, NavPers 10784.

Rocket propulsion has two noteworthy characteristics:

1. the propulsive force delivered is independent of atmospheric air, and thus the rocket may be propelled through empty space, and
2. the propulsive force is unaffected by the rocket's velocity.

9A2. BRIEF HISTORY OF ROCKETS

The use of rockets in warfare is not a recent development; in the thirteenth century they were used by the Chinese in the defense of Peiping against the Mongols. During the first two decades of the nineteenth century an Englishman, Sir William Congreve, developed artillery rockets that weighed up to 24 pounds. The rockets had a range of about 2 miles and were used by the British during the Napoleonic Wars and, in the history of our own country, during the attack on Fort McHenry in the war of 1812.

The revolutionary gun designs later in the nineteenth century, along with the development of smokeless powder, partially eclipsed the further development of rockets as a military weapon until World War II. During World War I, for example, rockets were largely restricted to such auxiliary jobs as signaling, and carrying lines in sea-rescue work; their only aerial offensive use consisted of tying them to the struts of French and Russian aircraft and shooting them into German observation balloons.

Beginning in the later part of 1941, the armed forces of Germany, Great Britain, and Russia came out with military applications of the rocket principle, all having worked on it for several years before the outbreak of war. Rockets were still much less accurate than guns, buy they made up for this shortcoming by the fact that they had no recoil and could be fired from a simple light launcher instead of a heavy gun. They could be used where absence of weight was desirable or a great volume of fire was more important than accuracy. Short-range rockets were developed for use against shore installations, ships, tanks, airplanes, and personnel. The Germans produced a long-range rocket missile known as the V-2.

By 1941 the United States had also embarked on a rocket program, and began rocket operations in the North African campaign of World War II with the Rocket Launcher M1, otherwise known as the bazooka. The year 1943 saw the first aircraft rockets used, and by the end of the war a variety of aircraft rockets were in combat use. The rockets to be taken up in this chapter are the present day descendants of these pioneers.

9A3. PRINCIPLE OF ROCKET PROPULSION

A rocket motor is a metal tube that serves as a combustion chamber. The burning propellant

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generates hot gas, and the gas pressure within the combustion chamber rises quickly to some value determined by the amount and characteristics of the propellant and the size of the nozzle or nozzles. The gas exerts approximately the same outward pressure on each square inch of surface within the combustion chamber; however, the gas rushes out of the nozzle without exerting any force upon the area of the opening, but with exertion of full force upon the corresponding area at the forward end of the combustion. Thus a net force or thrust acts in the forward direction.

In other words, a rocket meter is called a reaction motor because its operation is based on Newton's third law of motion: To every action (force) there is an equal and opposite reaction (force). This may be simply stated that the propelling force is the reaction of a force acting in the opposite direction. (An example is the recoil of a firearm when fired.) However, the operation of a rocket can be more simply and directly explained by a discussion of the pressures and forces within the rocket chamber.

Fundamental to rocket propulsion, then, is the conversion of heat energy into kinetic energy This poses two basic problems: (1) to generate gas under high pressure and at a constant rate-a problem of chemical reaction; and (2) to direct the high-pressure gases into a high-velocity stream-a problem of nozzle design. Pressure in a rocket motor depends largely on burning rate and escape rate. In solid-fuel rockets, for example, the composition of powder, shape of grain, and rate of burning, which have important relationships to performance as discussed in chapter 4, are also important factors in rocket design.

9A4. MAIN PARTS OF A TYPICAL ROCKET

Figure 9A1 shows the external appearance of one common type of rocket. The head of this rocket contains a high-explosive charge and a noze fuze to initiate detonation. The motor contains the combustion chamber, and houses the propellant charge. Hot gases from the combustion chamber issue from a nozzle at the after end of the assembly.

9A5. ROCKET MOTOR DESIGN

The thrust of a rocket motor is as stated, an equal and opposite reaction to the thrust developed by the expansion of gases discharged at the nozzle. Since the expansion of these gases is maximum in a vacuum, that is where rockets function most efficiently. (Rockets do NOT develop thrust by "pushing against" atmospheric air.) Rocket motors contain all the essentials for functioning, and do not require atmospheric oxygen for combustion.

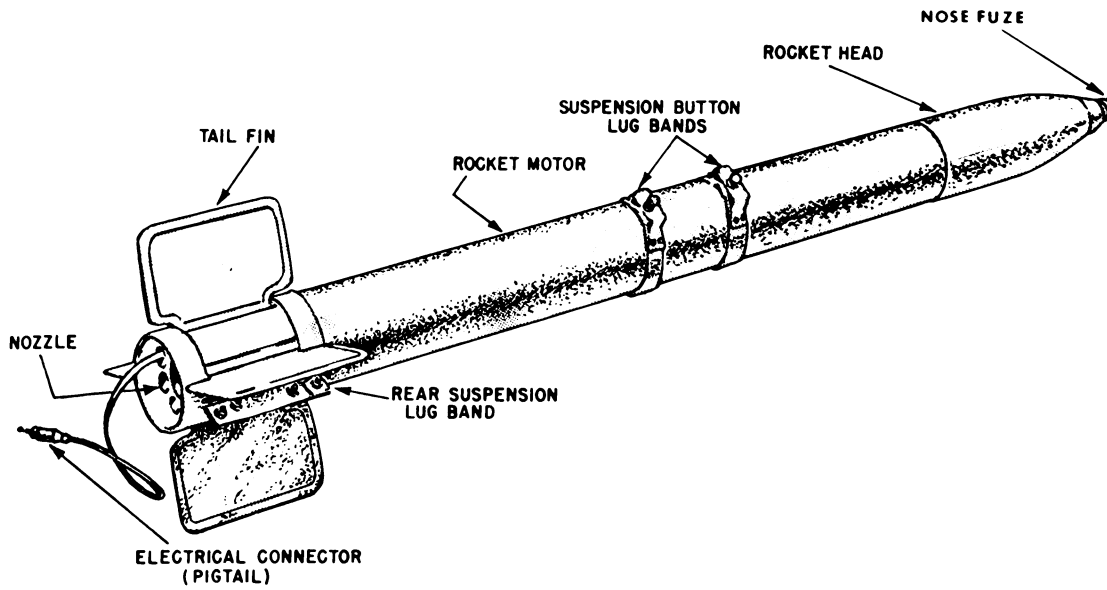

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Figure 9A1.—The 5.0-inch high-velocity aircraft rocket.

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The important functional parts of a rocket motor (in the types of rocket discussed in this chapter) are the nozzle, the motor tube, the propellant with its igniter, and the stabilizing features. First let us consider the nozzle.

NOZZLE. The function of the nozzle is to permit the hot gas produced by the burning ballistite propellant to flow out of the rocket motor, pushing the rocket along as it goes.

For maximum efficiency in developing thrust, gas flow must be nonturbulent (smooth). The shape of the nozzle determines the characteristics of gas flow, and hence has much to do with how efficiently the gas flow propels the rocket. For a smooth, controlled trajectory, the nozzle must produce thrust along the long axis of the rocket. And the nozzle must be designed to develop every possible bit of thrust from the flow.

By tapering the rear of the chamber so that it narrows smoothly toward the nozzle aperture, a smooth, nonturbulent flow of escaping gas is created. This tapered section forms the forward half of the nozzle. The tapered extension, forming the after end of the nozzle, which leads outward from the nozzle aperture, forces the escaping gas as it expands to furnish additional (about 33 percent) forward thrust (fig. 9A2).

Many rockets have a number of nozzles, rather than just one. The same principles apply there.

MOTOR TUBE. The rocket motor tube contains the propellant charge and igniter. It is a combustion chamber in which the propellant is burned to provide the motive power (hot gases) for the rocket. It generally threads to the rocket or an adapter in the base of the head, and is usually shipped separate from the head. The diameter of the motor is less than that of the head in some rockets; in others its diameter is about the same as the head's.

PROPELLANT AND IGNITER. The igniter contains black powder loosely packed, and an electric squib with a low-resistance bridge wire running through an initiating composition. (fig. 9A3).

All present types of rocket motors are initiated electrically. As figure 9A4 shows, the firing impulses may be transmitted either by a pigtail lead from the rocket plugged into a source of firing current, or by contact surfaces on the shroud surrounding the rocket's tail.

Navy rockets use solid propellants. The propellant is ballistite, either as (fig. 9A5) a single cruciform grain or as a single cylindrical grain with an axial hole and radial perforations. (Very large rockets may have up to four grains.) Grain size varies according to the motor in which the grain is used.

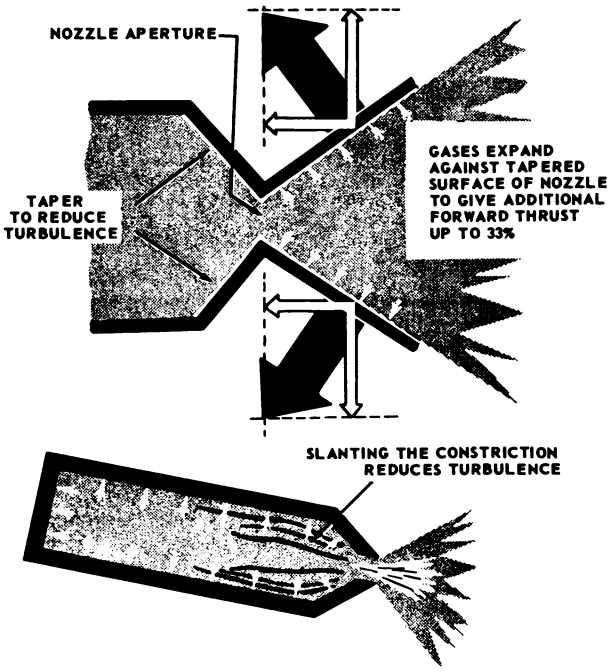

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Figure 9A2.—Features of rocket motor nozzle design. Schematic.

The cylindrical grain is characterized by three ridges spaced 120° apart and running longitudinally along the grain. The cruciform grain in section is a symmetrical cross. If all of the exterior surface of this grain were permitted to burn, there would be a gradual decrease of area, and the burning rate would be regressive-that is, the rate of gas production would decrease as the grain continued to burn. Since a uniform burning rate is desired, several slower burning plastic strips or inhibitors are bonded to certain parts of the area exposed on the outer curved ends of the arms. These slow the initial burning rate, and gas production rate is approximately uniform as long as the grain burns.

Hollow cylindrical grains have inherently uniform burning rates and usually require no inhibitors.

STABILIZING FEATURES. A rocket with its center of gravity forward of the nozzle is inherently unstable; if the propellent gas stream develops momentarily an off-center thrust component, or if the rocket as a whole is deflected

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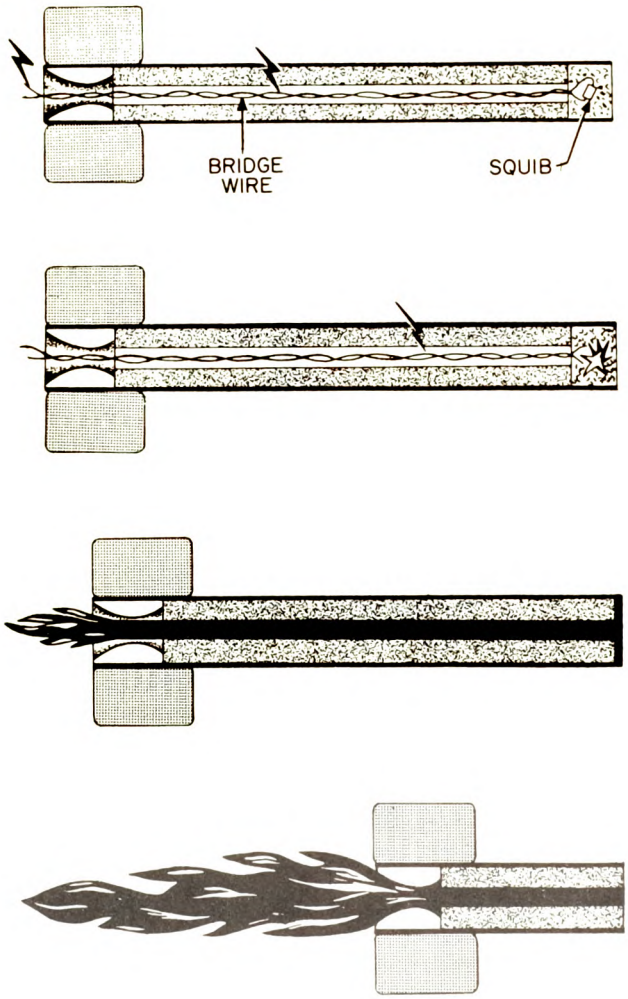

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Figure 9A3.—Igniter operation.

momentarily by some such accidental cause as a gust of wind, the rocket is likely to veer or even tumble. The classical 18th-century war rocket and its modern Fourth of July descendant used a stick protruding behind the rocket to stabilize it by moving its center of gravity aft. Modern war rockets are stabilized by fins.

Fins are fixed aerodynamic surfaces on the tail of the rocket. There are usually four, all at right angles to each other and parallel to the long axis of the rocket. (Figure 9B2 shows fins on aircraft rockets.) In some applications, the fins may be canted to twist the rocket so that it will spin. The parallel arrangement is more common, however. Note that fins (whether canted or straight) can be effective only when the rocket has sufficient air speed. (Folding fins that open upon launching are generally used to save space fig. 9A6). Fixed fins may be surrounded by a cylindrical shroud which helps to support the rocket in its launcher.

9A6. ROCKET HEAD DESIGN

The rocket head is the explosive or destructive part of the rocket. It is constructed as a separate unit and assumes a variety of forms depending on the application. Rocket heads are classified according to their function and are discussed in the following paragraphs.

GENERAL PURPOSE. These are relatively thin-walled heads containing about 30 percent of explosive by weight. These heads have a large blast effect and their penetration ability against light armor is good. Rockets with this type of head have either a nose detonating fuse or a steel nose plug and base fuze. (Fig. 9A7A.)

HIGH EXPLOSIVE. High explosive heads are similar to general purpose heads except that only nose detonating fuzes can be used with them (fig. 9A7B).

SHAPE CHARGE. These heads are thin walled and contain a high percent of explosive by weight. The shape-charge cone in the head has good blast and fragmentation ability, and the shape-charge jet penetrates deeply into armor and concrete. Rockets with this type of head (fig. 9A7C) are used against tanks, trains, heavy vehicles, and armored installations where explosion inside the target is not required.

ARMOR PIERCING. Armor-piercing heads are thick walled and are designed for maximum penetration. They usually contain less than 10 percent of explosive by weight, and have a base detonating fuze. This small percent of explosive results in a correspondingly small blast effect (fig. 9A7D).

PRACTICE. These heads are intended for training in rocket firing or for testing fuzes and motors (fig. 9A7E).

As previously noted, the head of a conventional rocket contains a high explosive charge capable of being detonated by action of a fuze or fuzes. Use of centrifugal force and setback to arm fuzes, as in gun projectiles, is not universally applicable to rocket fuzes. In part, this is because rockets accelerate at a lower rate than do gun projectiles; moreover, with fin-stabilized rockets no centrifugal forces are available. Hence various other methods are employed to arm rocket fuzes. The fuzes of some antisubmarine rockets, for example, are armed

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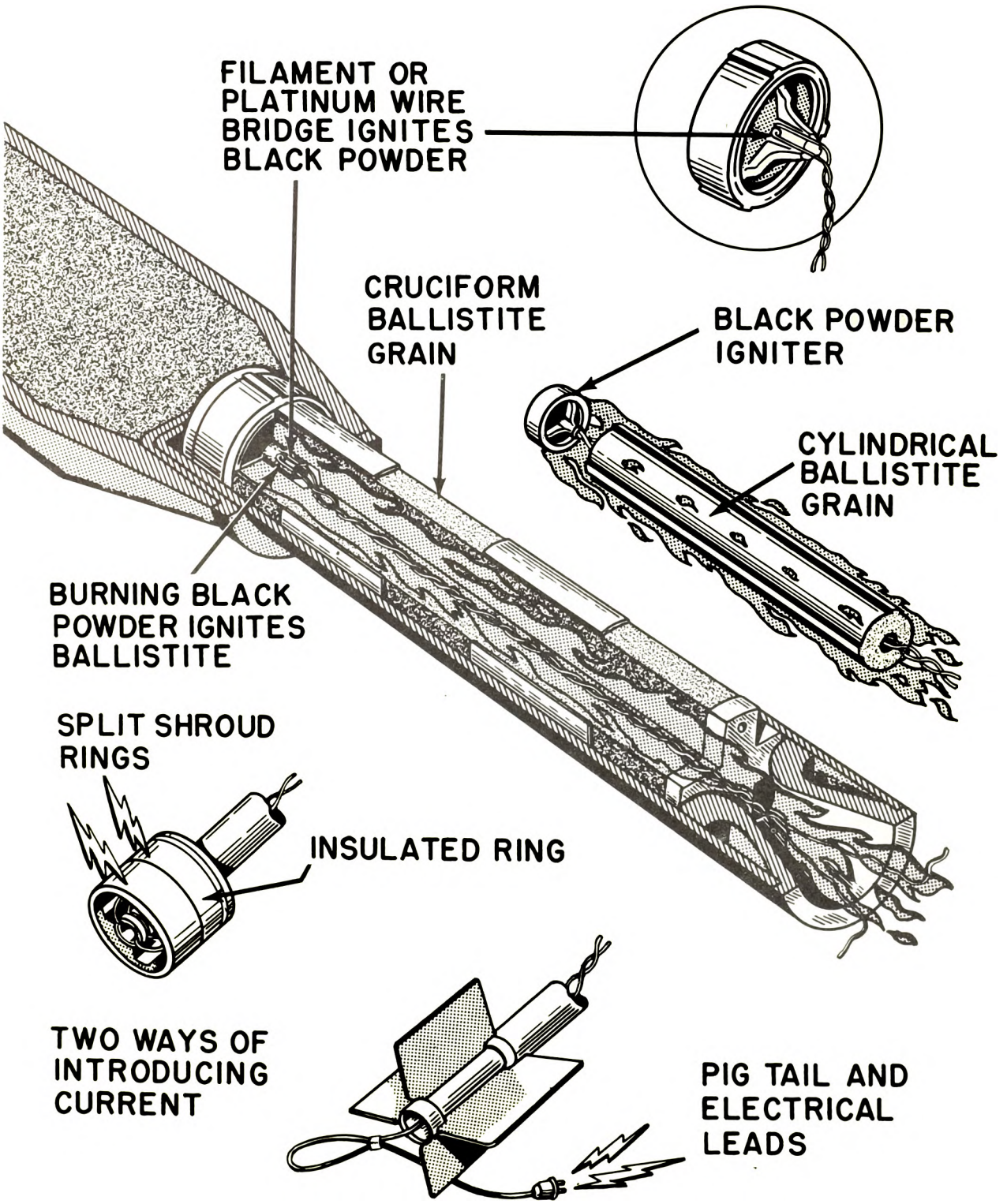

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Figure 9A4.—Rocket motor propellant and igniter details.

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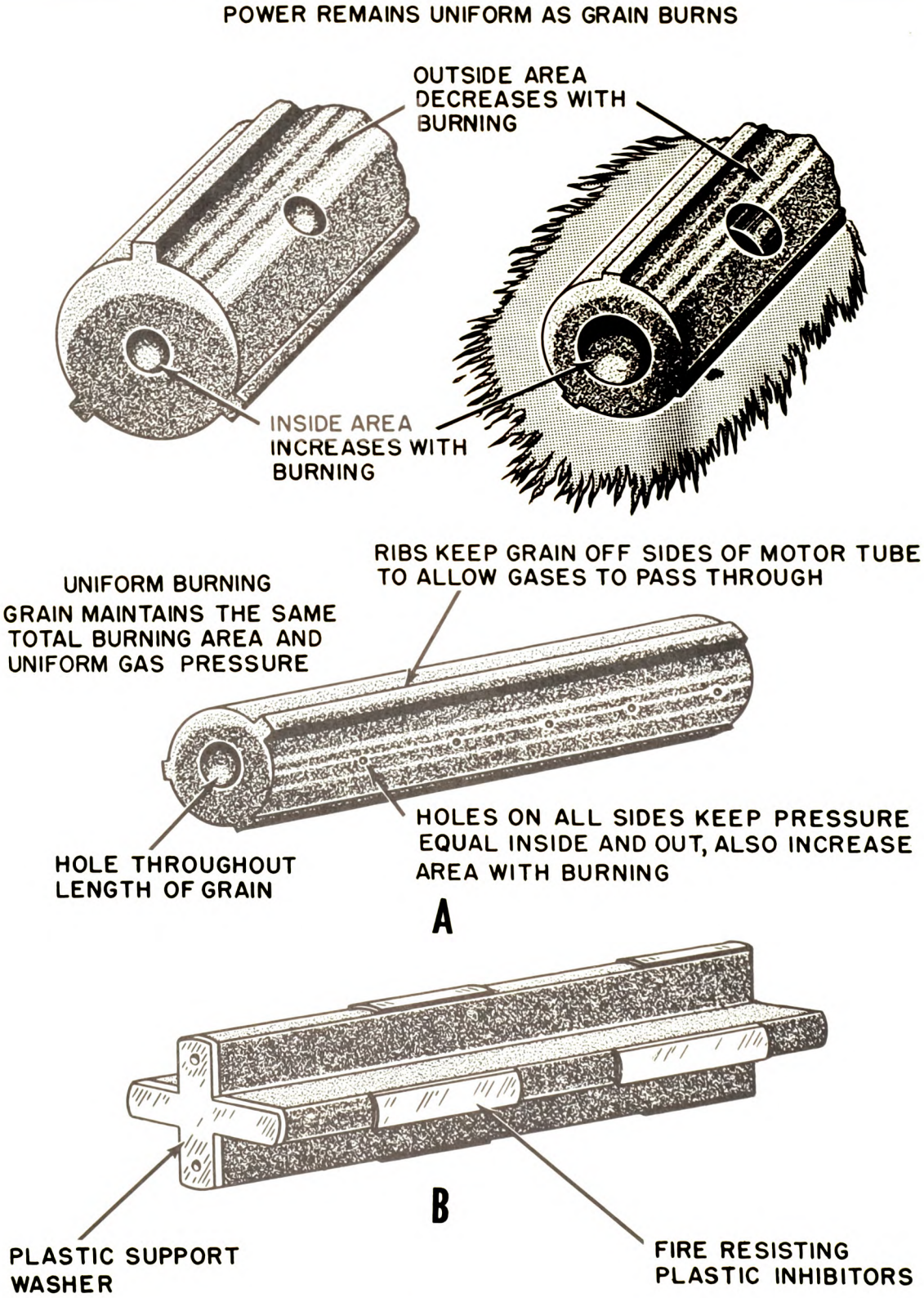

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Figure 9A5.—Rocket motor grains. A. Cylindrical; B. Cruciform.

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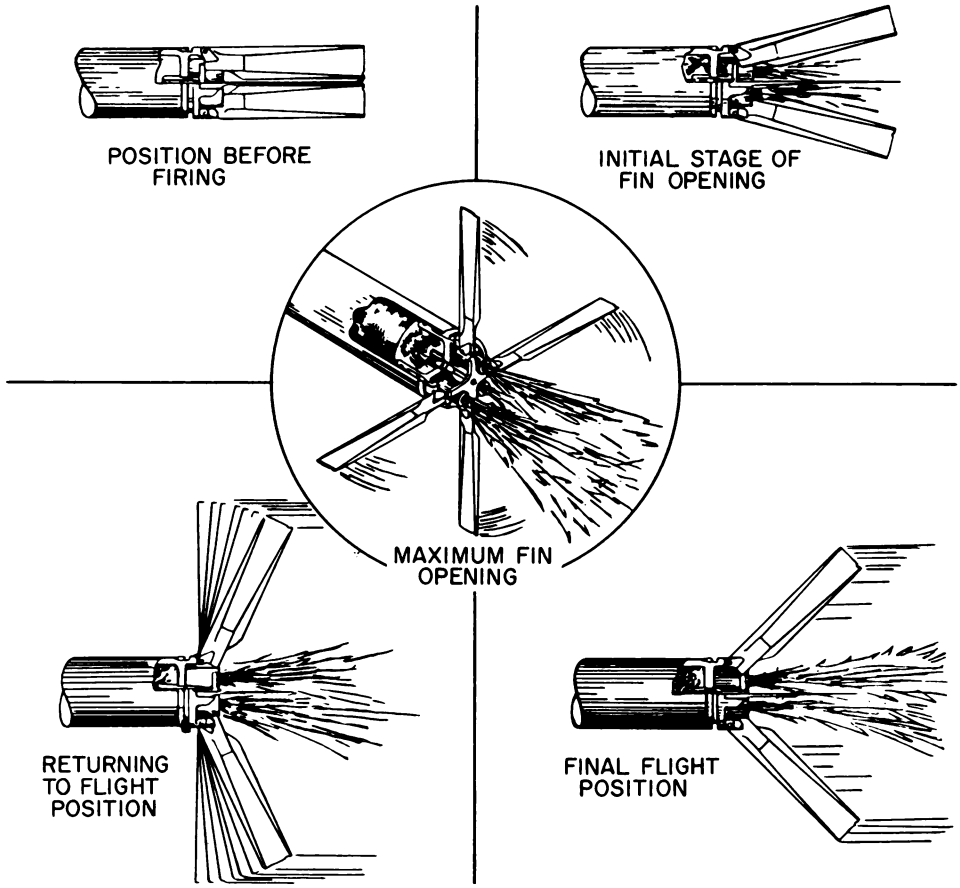

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Figure 9A6. Phases of folding fin operation.

either by hydrostatic pressure or by rotation of a propeller after travel of 15 to 20 feet in the water. When armed, such rockets detonate upon impact with any solid object. Several methods have been utilized to arm rocket fuzes so that they will detonate upon impact or after a predetermined delay. In one type of nose fuze, arming depends upon rotation of a small propeller as the rocket moves through the air. A base-detonating type is armed by a mechanism that is actuated by pressure in the rocket during burning.

9A7. ROCKET LAUNCHERS

Modern rockets are fired from various types of launchers. These in essence are mechanisms designed to point the rocket in the right direction and to actuate or ignite the motor. One significant fact about launching is that there is little or no recoil. The forward momentum given to the rocket is balanced by the rearward escape of propellent gases. Therefore, a very large total weight of "pay load" may be fired from boats, airplanes, or other vehicles which could not possibly withstand the recoil shock incident to firing equivalent projectiles from traditional types of larger guns. This is why the development of aircraft rockets, to cite one example, has been so significant. Inability of aircraft structure to stand up under the recoil shock of conventional-type guns had long been a limiting factor in aircraft armament. Until the rebirth of military rockets occurred, the largest projectile fired by most aircraft guns weighed only 2 or 3 pounds. The modern rocket-firing plane, however, is capable of launching rockets which weigh over 1000 pounds.

It also is noteworthy that many rocket launchers are relatively light in weight, simple, inexpensive, and more readily replaceable than

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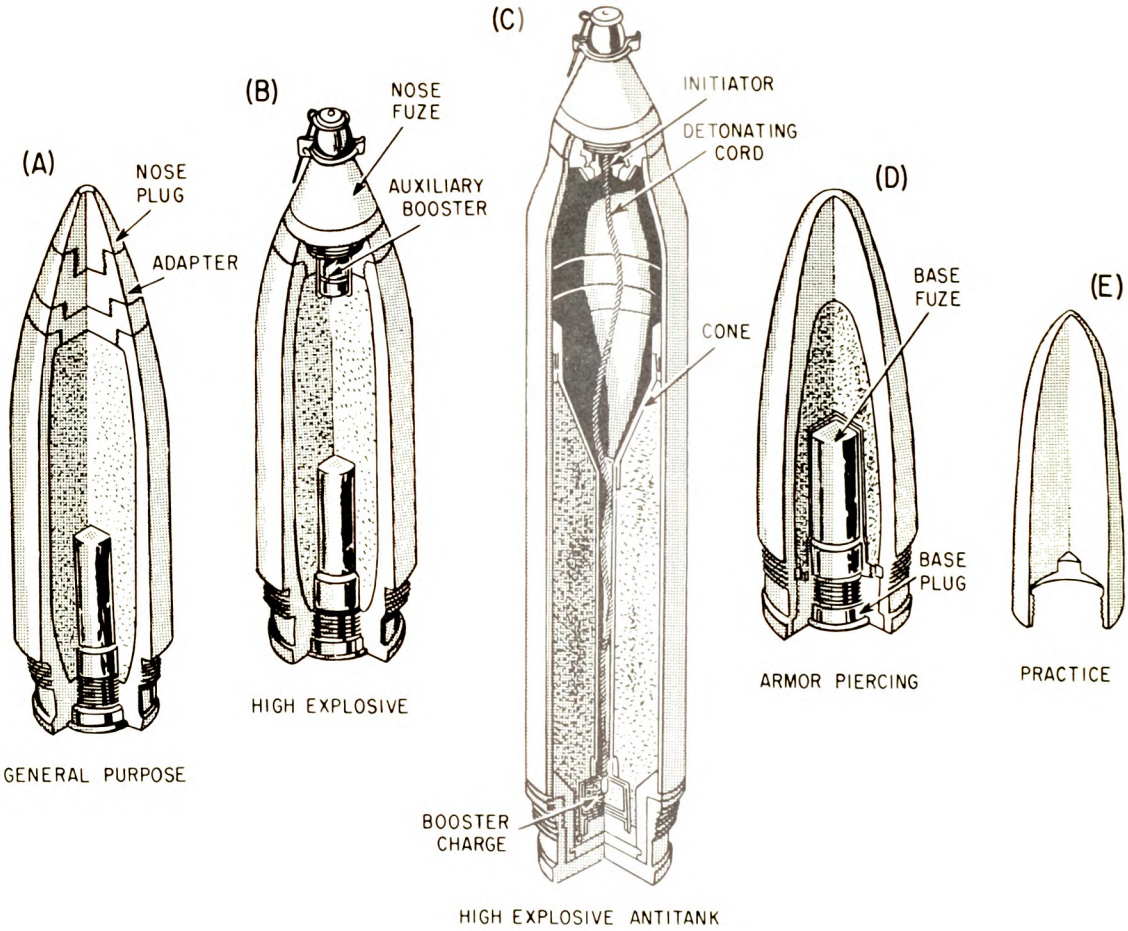

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Figure 9A7.—Aircraft rocket heads.

comparable guns. On the other hand, much more propellant is required to bring a rocket up to a given velocity than is the case with a gun projectile. Moreover, rocket fire (with conventional short-range rockets) launched from the ground or from the deck of a ship compares unfavorably in accuracy with gunfire.

Shipboard rocket launching devices always have a tube or rail which supports the rocket until firing, and guides it during the critical initial portion of its trajectory. This is necessary because the stability of the rocket is relatively poor until it attains a fairly high air speed.

On fixed-wing aircraft, as has already been explained, fin stabilization of rockets is effective at the instant of launching because of the plane's air speed. Rocket launchers in aircraft are therefore merely supports which hold the rocket until launching, and then release it as the propellant is ignited. These are called "zero length" launchers.

9A8. ROCKET TRAJECTORY CHARACTERISTICS AND ACCURACY

It has already been noted that conventional rockets are less accurate than gun projectiles. For example, the horizontal dispersion of fin-stabilized rockets fired from aircraft is on the order of 6 to 8 mils; comparable dispersion of gun projectiles is 1 mil or less. One reason for this is that gun projectiles are guided by the gun bore during the entire period in which the propellant is burning and maximum velocity is being attained. A rocket, on the other hand, is guided by its launcher, if at all, during only a very small portion of the time that its propellant burns; in all cases, maximum velocity of the

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rocket is attained after it has left the launcher, and in some cases after the rocket has passed through hundreds of feet of free flight. In addition, the center of gravity of a gun projectile remains fixed in position in relation to the projectile while the latter is in flight, whereas the center of gravity of the rocket necessarily shifts in relation to the rocket as the fuel in the motor is consumed.

After a rocket has attained maximum velocity, it may traverse a trajectory similar to the path traversed by a gun projectile. On the other hand, it is possible to place lifting surfaces (wings) on the rocket head, which will cause the missile to follow a glide path rather than a purely ballistic path, once acceleration is completed.

Rockets have proved to be extremely valuable weapons for special purposes. Examples include the employment of rockets in antisubmarine attacks, and the saturation of enemy-held beach positions by rocket fire launched from airplanes.

9A9. ROCKETS IN CURRENT USE IN THE U.S. NAVY

Rockets fired by naval ships and aircraft are designated by head diameter in inches. (This is analogous to the caliber of gun projectiles.) The motor may be the same size as, or smaller than, the head, but never larger.

Several types of rocket of 4-inch and smaller caliber are used for practice firing, as targets at which other weapons can fire, or for signaling. Subcaliber rockets which fit into the launchers of larger types and are used as inexpensive substitutes for training purposes are also in this range of sizes.

Aircraft rockets intended for use against enemy targets or for other combat use are at present made in 2.75-inch and 5.0-inch sizes. Rockets fired from surface craft include the 12.75 inch rocket (Weapon alfa) and ASROC (Anti-submarine rocket). SUBROC (Submarine rocket) is usually fired from a submerged submarine. However, these rockets are designed primarily as launching devices for a/s charges, and thus will be discussed in the ASW chapter 10.

The old 5.0-inch spin-stabilized rockets fired from rocket launching ships of World War II fame are no longer in use throughout the fleet.

9A10. GENERAL SAFETY PRECAUTIONS IN HANDLING AND FIRING ROCKETS.

1. Review of ordnance instructions. Frequent review of ordnance pamphlets and the latest ordnance instructions pertaining to each piece of equipment should be made mandatory by all authorities in command of units afloat and ashore, wherever rockets are stowed, assembled, or fired.

2. Nozzle blast. It should be remembered that nozzle blast from a rocket motor is intensely hot. Small pieces of burning powder frequently are blown out of the nozzles and may be hard to extinguish. Steel sheathing is therefore used to protect decks and superstructure areas around launchers. Some launchers (Weapon Alfa) have blast deflectors for protection of the immediate area. It is obviously unsafe for any one to be directly in front of or behind a loaded launcher, or one that is being loaded. Personnel loading a launcher should always stand to one side of the path that would be taken by rocket or blast, in the event of accidental or intentional firing. All personnel in the vicinity of a launcher should wear long trousers, and long shirt sleeves buttoned about the wrists.

3. Firing precautions. The firing circuit must be open at all times until the launcher is ready to fire. All extra rockets must be kept at a safe distance from loaded deck-mounted launchers. No personnel may approach a loaded launcher until the safety plug or firing key has been removed from the firing circuit. The fuze safety wire must be reinserted as soon as the safety plug or firing key has been removed, but not before. No test of the firing circuit may be conducted until all rockets have been removed from the launcher and placed at a safe distance. Naked lights, matches, or other flame-producing apparatus must never be allowed in the vicinity of rocket ammunition.

4. Fuzes. At no time are any personnel permitted to attempt disassembly of an armed fuze. Such a fuze must be disposed of. A base fuze should never by removed outside of an ordnance depot. Always ensure that the base fuze is in place before firing.

5. Propellant grains. Under no circumstances may a propellant grain be removed from a motor. No surveillance tests are made of rocket propellants.

Other safety precautions are detailed in appropriate ordnance publications and in appendix C of this volume.

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B. Rockets Fired From Aircraft

9B1. HOW ROCKETS ARE USED ON AIRCRAFT.

Aircraft rockets are used primarily as forward-firing weapons, which supplement or take the place of forward-firing guns. The virtual absence of recoil in launching aircraft rockets makes possible the use of lightweight gear for such launching, and introduces no stresses inimical to the plane's structures. A modern rocket-firing plane armed with 5.0-inch rockets can deliver one salvo comparable to that of a destroyer. In making such a comparison, however, it must be remembered that the ships can keep on firing, whereas the planes must return to base after delivering their payloads. Generally speaking, rockets provide superior firepower with minimum added weight. The payload of a rocket is less than that of a comparable bomb, but the rocket presents advantages related to accuracy of fire and greater penetration.

Rocket velocity is augmented by the velocity of the launching plane, with the result that actual velocities attained approach those of comparable projectiles. This accuracy increases with increased speed and stability of the aircraft at the time of release. In antisubmarine use, the underwater trajectory of rockets is predictable, and this fact can be used to advantage.

Special types of aircraft-borne rockets are used to drop beacons, smoke pots, and the like. These are not weapons and are consequently not described in this book.

The rocket's reaction principle of propulsion is also used to provide extra thrust to assist aircraft in taking off with abnormally heavy payloads and when length of takeoff is restricted. The special JATO (jet-assisted takeoff) units used for this application, through they work on the rocket principle, are not weapons and are not taken up in this course.

9B2. AIRCRAFT ROCKET TYPES

Basic types of aircraft rocket include a 2.25-inch training rocket (SCAR), the 2.75-inch air-to-air (FFAR), the 5.0-inch high-velocity rocket (HVAR), and the 5.0-inch "Zuñi." Other rocket-propelled weapons such as the "Sidewinder" are guided missiles and are taken up in the second volume of this series.

The paragraphs below briefly describe these rocket types, except for those used only in training.

9B3. 2.75-INCH AIRCRAFT ROCKET

The 2.75-inch FFAR—for "Folding Fin Aircraft Rocket"—is a contact-fuzed air-to-air rocket with folding fins that open on launching (fig. 9B1, part A). It is small enough to be carried in quantity; but, with a direct hit, one round can destroy a plane. The rockets are carried in either of two types of streamlined cylindrical jettisonable launchers with paper noses and tails which offer minimum obstruction to the passage of the rockets and their motor blast. One model of this launcher carries 7 rockets; the other carries 19. Both models are suspended under the wing of the aircraft, as shown in figure 9B1, part B. (The 19-round rocket launchers are shown with noses removed; the smaller launcher on the left with its nose in place is the 7-round rocket unit.) The rockets are fired either singly or in quick succession through the launcher's easily penetrable nose. When the rockets are expended the launchers can be jettisoned.

9B4. 5.0-INCH AIRCRAFT ROCKETS

There are two types of 5.0-inch aircraft rocket—the HVAR (High-Velocity Aircraft Rocket) and the "Zuñi."

The 5.0-inch high-velocity fin-stabilized rocket (1,375 ft. per sec.) can penetrate 6 feet of concrete. It is used against ships, pillboxes, locomotives, and tanks. Its head is a 5-inch common projectile, with nose and base fuzes and a 7.9-pound charge of TNT. The propellant is a 24-pound grain of ballistite. One type of head available with the 5.0-inch aircraft rocket is designed for water entry at high velocity, and will penetrate a submarine hull after traveling underwater. As figure 9B2 shows, the rockets are mounted singly on external launchers under the aircraft wing.

The Zuñi rocket (fig. 9B3, part A) is designed for both air-to-ground and air-to-air attack. The rocket is 110 inches long, weighs 107 pounds, and has a high-performance motor with an internal-burning solid-propellant grain. Rocket

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velocity is twice that of the HVAR. Jet-operated radially folding fins stabilize the rocket's flight. A selection of interchangeable war heads is available for use against a wide variety of targets. A novel type is a "flare head" which functions more or less like an illuminating projectile to illuminate 2 square miles of the earth's surface. Zuñi fuzing provides an option of influence, contact, or time-delay detonation.

Each under-wing rocket launcher ripple-fires four Zuñis or, at pilot option, fires the rounds singly. The launcher is reusable and also serves as a shipping container for the motors only. (Fig. 9B3, part B.) Because of Zuñi's folding-fin feature, with this launcher an aircraft can carry four times as many Zuñis as HVAR's. Zuñis are gradually replacing HVAR's in the Fleet.

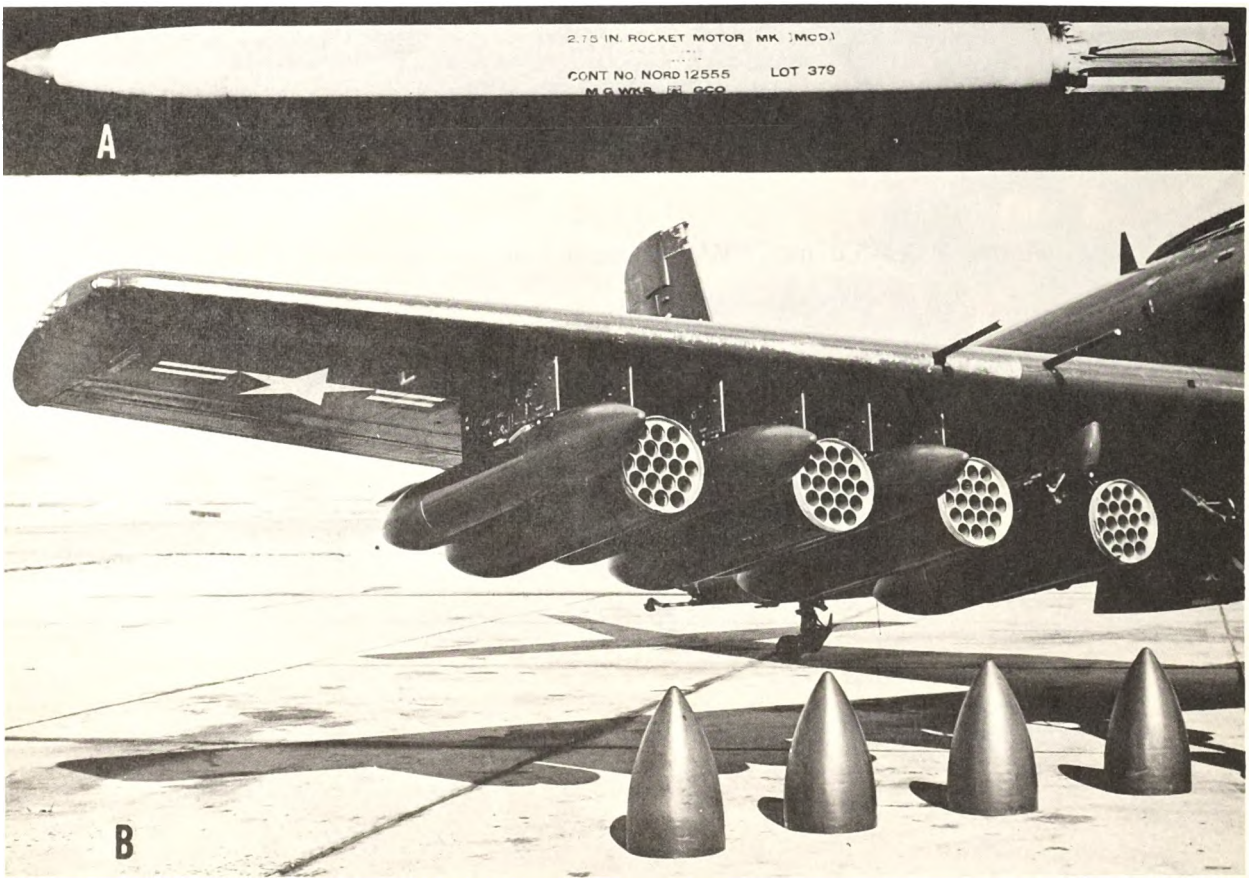

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Figure 9B1.—2.75-inch FFAR rocket. A. Closeup, wings folded; B. 7- and 19-round launchers suspended from aircraft. (Noses removed from 19-round launchers.)

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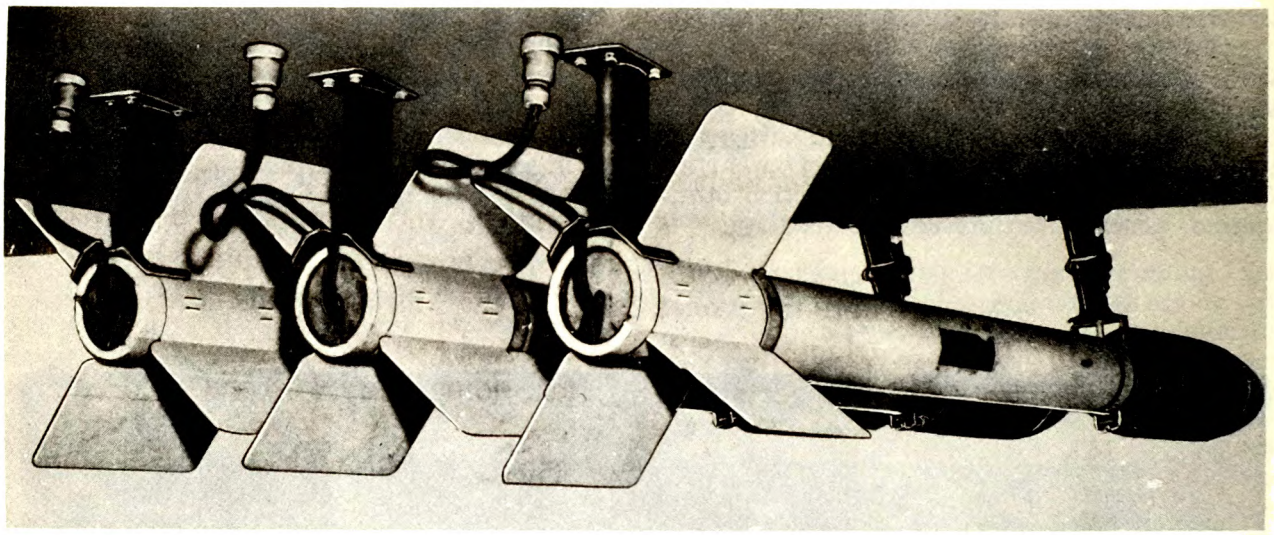

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Figure 9B2.—5.0-inch HVAR on zero-length under aircraft wing.

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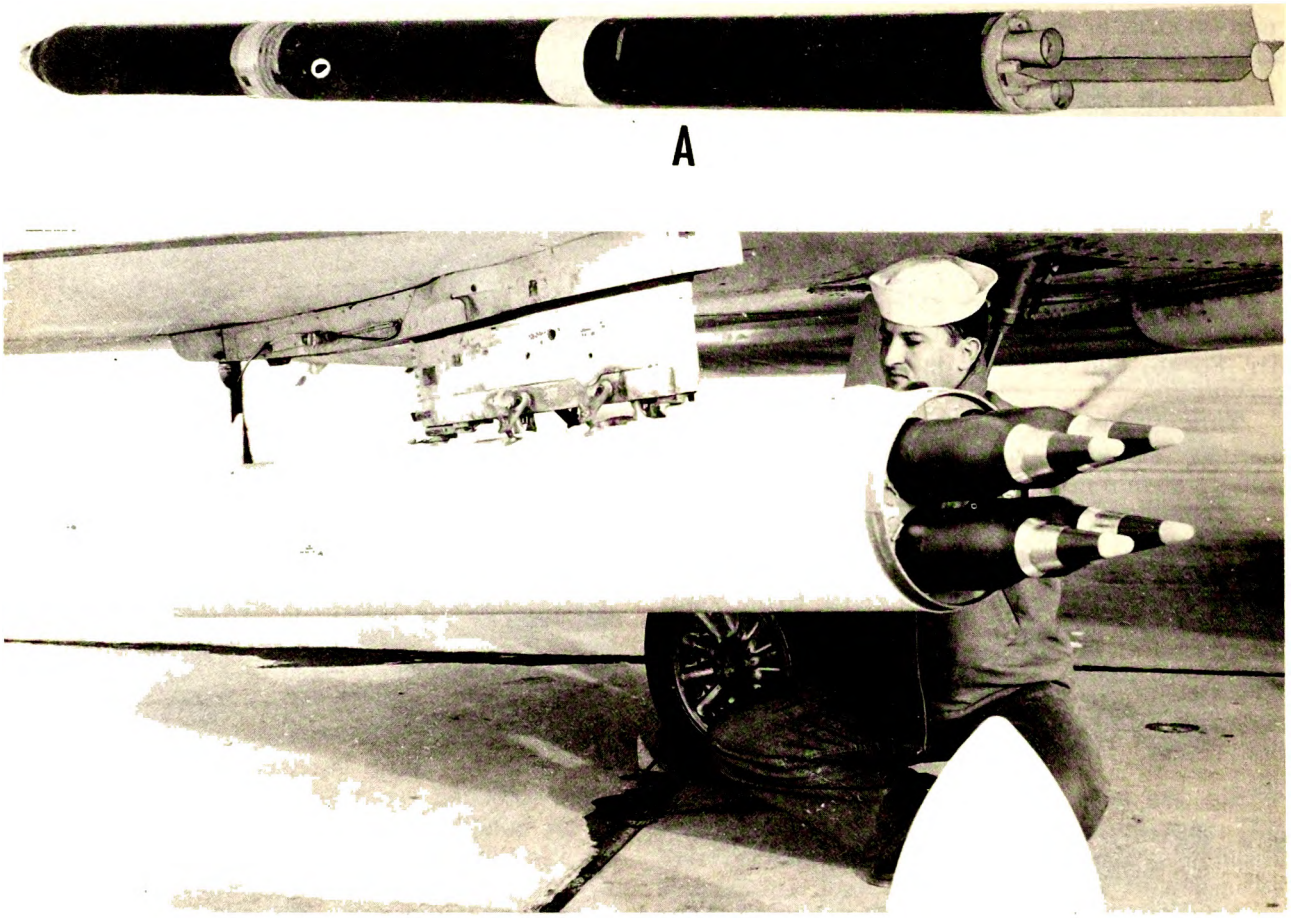

A

B

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Figure 9B3.—Zuñi rocket. A. Closeup, fins folded; B. Loaded Zuñi launcher.

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C. Aircraft Bombs

9C1. GENERAL

Aircraft bombs are weapons designed to be dropped upon enemy targets to reduce and neutralize their war potential by destructive explosion, fire, or nuclear reaction. They are used strategically to destroy installations, armament, and personnel, and tactically to provide direct support of our land and sea forces engaged in offensive or defensive operations. Bombs are procured both by the Navy and the Air Force, and are used in common by the two services.

This chapter does not take up nuclear bombs. Nuclear weapons are discussed in the second volume of this series.

A bomb usually consists of a body, stabilizer, and means of detonation. The body can be filled with either an explosive, chemical, nuclear, or inert filler. Stabilizers are attached to the bomb body and may consist of sheet-metal fins, parachutes, or cloth streamers. The efficient destruction of the various types of enemy targets requires different types of bombs (fragmentation, blast, incendiary, semi-armor-piercing, etc.).

9C2. EXPLOSIVE AND OTHER CONTENTS OF BOMBS

A fundamental characteristic required of the explosive charge of a bomb is relative insensitivity to ordinary shock and heat incident to loading, transporting, handling, and storing. This insensitivity permits:

1. adequate safety for using personnel (when the explosives are handled properly);
2. maximum target damage by control of the bomb's detonation;
3. jettisoning bombs from aircraft without exploding, in emergency.

It is evident that these requirements, as with gun projectiles and other explosive devices, make it necessary to use an explosive train in aircraft bombs. In most bombs, the train begins with a detonator containing a small amount of very sensitive explosive. (The detonator is part of the bomb's fuze.) The detonator sets off a rather less sensitive booster; in turn the booster explodes the main charge.

In addition to the different types of explosives required in the individual components of the explosive train of any single bomb, the main charge of any bomb is made up of different explosives, depending on the purpose of the bomb. High explosives used in present types of bombs include TNT, Amatol, Composition B, Explosive D, Tritonal, and HBX. Chemical agents are chiefly napalm and thermite. The characteristics of these explosives and chemical agents, and of explosives used elsewhere in the explosive trains of aircraft bombs, are described in chapter 4 of this volume.

9C3. EXTERIOR CONFIGURATION OF BOMBS

The aircraft bombs used during World War II and shortly thereafter were designed primarily to provide space for as much bursting charge or other payload as possible without compromising simplicity of manufacture or satisfactory streamlining. This approach resulted in a gratifyingly efficient container whose silhouette was short, compact, and stubby (as can be seen in fig. 9C1), economical of bomb-bay space, and aerodynamically efficient enough to make the bomb ballistically reliable (i.e., when released from an aircraft under a given set of conditions, it could be depended upon always to land in the same locality).

For subsonic aircraft, this constituted satisfactory performance. But when the speed of bombardment aircraft exceeded that of sound, the hitherto satisfactory bomb shape was found to be poorly adapted to the new conditions either when the bomb was slung under the aircraft's wing or fuselage, or when it was released. Not only was the bomb now a serious detractor from aircraft performance (if carrier outside the fuselage) but it could no longer be dropped as accurately. Besides, the mechanical arming wire arrangement used to control bomb fuze arming was apt to tear loose or foul the bomb or parts of the aircraft, causing the bomb either to become a dud or to arm prematurely and become a menace to the aircraft carrying it.

It then became necessary to redesign the aircraft bomb so that it would be satisfactorily streamlined at sonic and supersonic speeds, and so that its fuze's arming could be reliably controlled without danger of its vital parts being damaged by high air speeds. To solve the first problem, the bomb's exterior shape was altered to give it minimum drag at high speed. To solve

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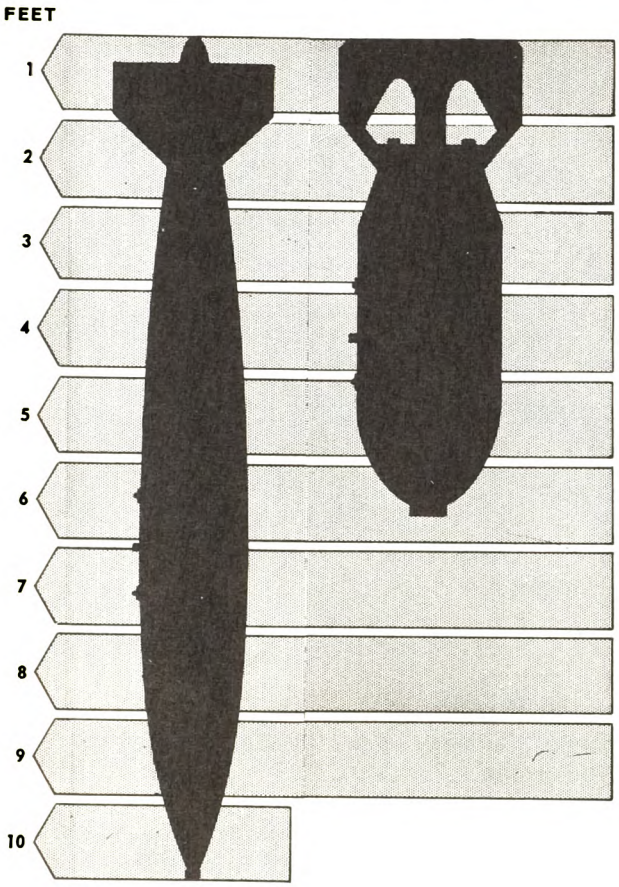

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Figure 9C1.—Silhouettes of a low-drag bomb (left) and a conventional bomb (right).

the second, an internal electrical fuze control system was provided that could be substituted for the conventional mechanical system.

Figure 9C1 compares the silhouette of a 1000-pound conventionally shaped practice bomb (on the right) with that of a low-drag bomb of the same weight (on the left). The flat forward end on the low-drag bomb indicates that it is set up for a mechanical fuze arrangement. A low-drag bomb set up for electric fuzing has a smoothly streamlined nose that comes to a point.

9C4. BOMB COMPONENT NOMENCLATURE

A COMPLETE ROUND denotes a bomb with all its components as it is suspended from the rack or shackle of the aircraft ready for flight. Some of the major components of bombs are listed below and illustrated in figures 9C2 and 9C3 for conventional and low-drag bombs respectively.

BOMB BODY. The bomb body is the container that holds the filler. This filler may be either explosive, incendiary, or chemical.

FIN ASSEMBLY. The fin assembly is the flight stabilizer of the bomb and usually is made of sheet metal. In newer types of bombs, a conical fin assembly with better aerodynamic properties is used (fig. 9C3) in place of the older box type (fig. 9C2).

FUZE. Fuzes initiate bomb detonation. They contain sensitive explosives and should be handled accordingly.

ARMING WIRE ASSEMBLY. This consists of either a single or doubts wire attached to a swivel loop, and is used to keep the fuzes safe prior to release of the bomb from the aircraft.

SUSPENSION LUGS. Suspension lugs may be either welded to, bolted on, or screwed into the bomb body. Lugs for double-look racks are either 14 or 30 inches apart, depending upon the size of the bomb. On bombs currently in use, a lug for single-hook suspension is located on the side of the bomb body opposite the double lugs. In the new series of Air Force bombs and low-drag Navy bombs, it is located midway between the double lugs.

HOISTING LUGS. These lugs are either welded to or screwed into the bomb body. The hoisting lug usually is located between the double suspension lugs, and is used for hoisting the bomb to the aircraft's bomb shackle or hook.

9C5. BOMB IDENTIFICATION

All standard bombs used by the Navy and Air Force are identified by the prefix AN- followed by the mark and mod as already mentioned in chapter 1 of this text. AN means ARMY-NAVY, and indicates that an item has been standardized for joint use by both the Navy and Air Force. The letter M following the AN (AN-M66) shows the item was an Army development. A Navy-developed item is indicated by MK or Mark following the AN, such as AN-MK230. Subsequent modifications to an Army (or Air Force) developed item are indicated by letter A, followed by a number; for example, AN-M66A1 would indicate a first modification, AN-M66A2 the second modification, and so on. Modifications to a Navy-developed item are indicated by Mod (modification) followed by a number such as AN-MK230 Mod 0, which would be the original design, AN-MK230 Mod 1, the

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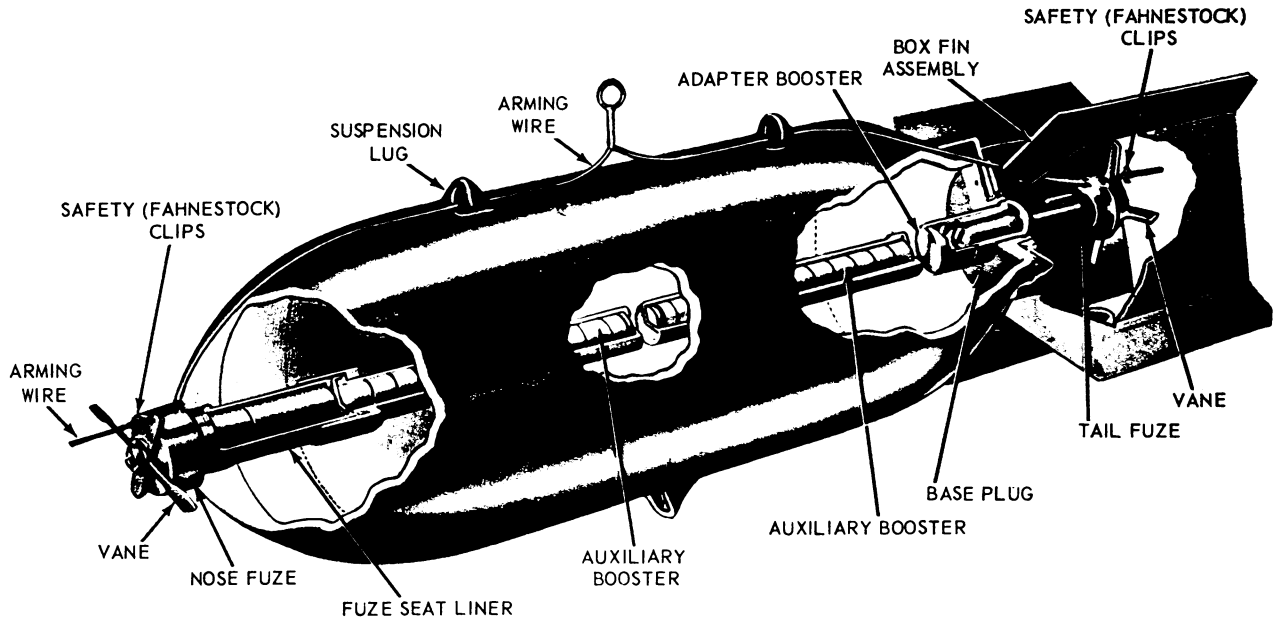

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Figure 9C2.—Conventional general-purpose bomb. Cutaway view. (Filler omitted to reveal details of arrangements.)

first modification etc. AN numbers, along with basic nomenclature, lot numbers, etc., are stenciled on all bombs, bomb components, and packing materials. In addition, bomb bodies are painted and marked in various color schemes for identification. (Fig. 9C4).

9C6. LOADING FACTOR

An explosive bomb can do its damage through two effects—fragmentation and blast. Its effectiveness as a destructive agent often depends, however, on its ability to penetrate an armored target before detonation. (In this it resembles an AP projectile.) On the other hand, there are instances in which penetration is unimportant because it is sufficient for the bomb merely to get close to its target, just as an AA projectile need not score a direct hit to cause damage.

These factors all have much to do with how a bomb is designed. A bomb with a thick heavy case, for instance, will be able to penetrate much farther than a bomb with a thin case. But because most of the weight of such a bomb goes into the case, it cannot carry as much explosive, and so has less blast effect.

If the walls of the case are thin, there will be room for a large load of explosive. The blast effect will be great, both the case will have little strength, and the bomb will not penetrate. Besides, there will be less fragmentation effect because there is not enough metal in the case to provide many fragments.

From this it is clear that, if you know what percentage of the weight of a bomb is taken up by the explosive, you can tell quite a bit about its characteristics and uses. This percentage is called the loading factor of the bomb. More exactly, it is the ratio of the weight of explosive to the total weight of the bomb. If the total weight of a bomb is 1000 pounds, say, and it contains 500 pounds of explosive, it will have a 50 percent loading factor. If it contains only 150 pounds of explosive, it will have a 15 percent loading factor.

What, then, is the best loading factor for a bomb? That depends on what the bomb is to do. To demolish a row of masonry buildings, you want the most blast possible—hence you need a high loading factor. For a bomb to get through the deck armor of a cruiser you must have a massive case for great penetration power, and that means less explosive and a low loading factor.

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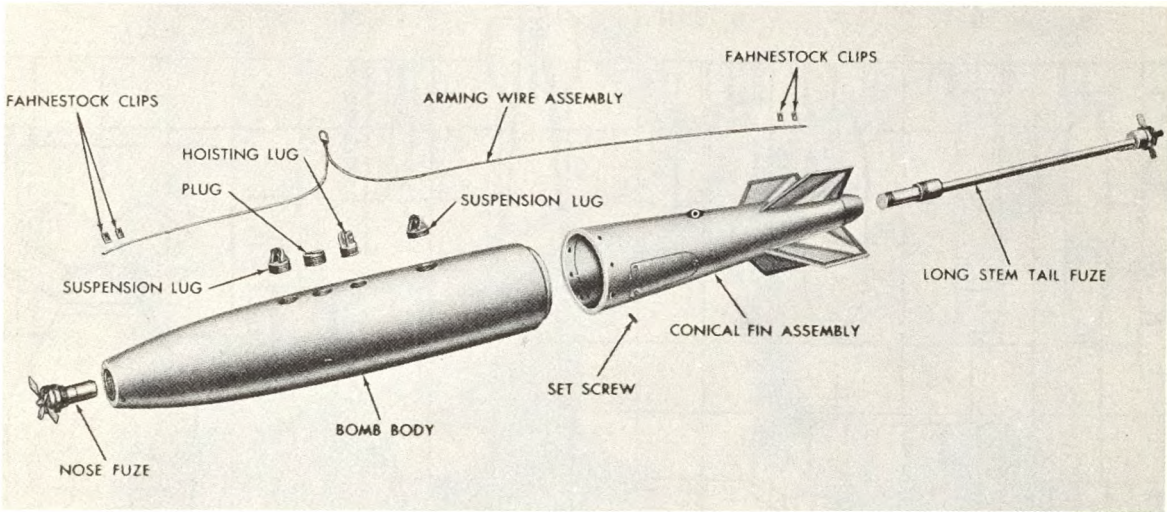

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Figure 9C3.—Low-drag general-purpose bombs, mechanically fuzed. Exploded view.

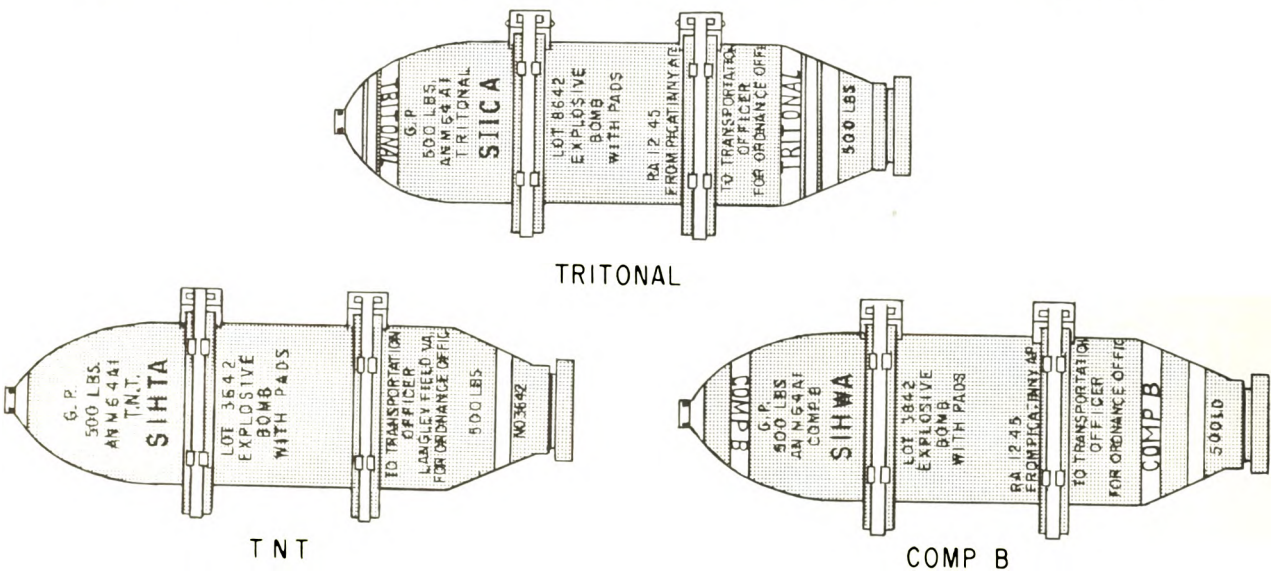

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Figure 9C4.—General purpose bombs with typical markings.

9C7. CLASSIFICATION OF BOMBS

Aircraft bombs are classified according to filler as follows:

1. High explosive
2. Fire
3. Drill
4. Practice
5. Chemical

High-explosive bombs, in turn, are classified according to use:

1. Semi-armor-piercing (SAP)
2. General purpose (GP)
3. Low-drag general purpose (low-drag GP)
4. Fragmentation (Frag)
5. Aircraft depth (AD)

Figure 9C5 illustrates conventional bombs of the various classifications discussed.

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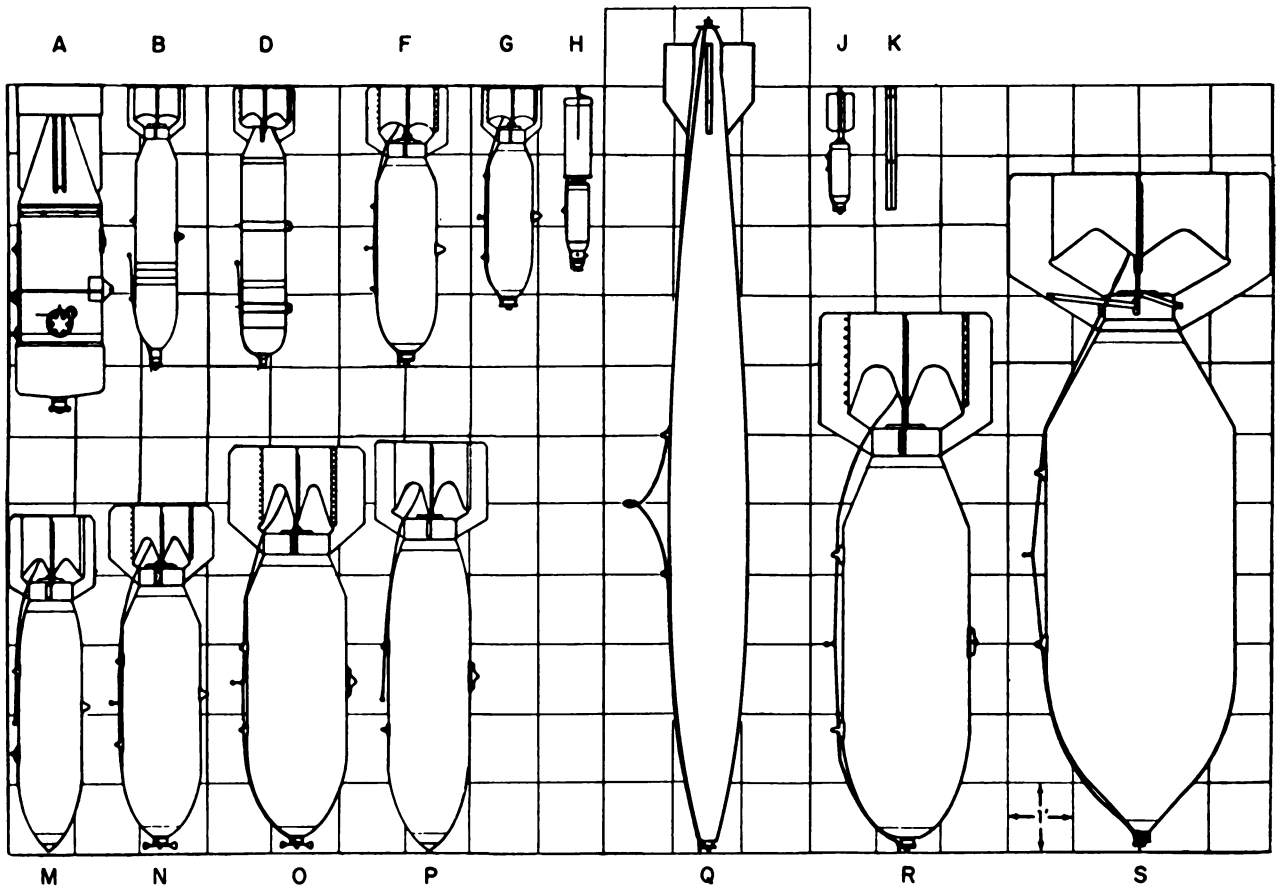

(A) DEPTH BOMB-325 LB.-FLAT NOSE
(B) GAS BOMB-115 LB.
(D) CHEMICAL BOMB-100 LB.
(F) G.P. BOMB-250 LB.
(G) G.P. BOMB-100 LB.
(H) FRAGMENTATION BOMB-23 LB.
(J) FRAGMENTATION BOMB-20 LB. (for cluster)
(K) INCENDIARY BOMB-4 LB.
(M) S.A.P. BOMB-500 LB.
(N) G.P. BOMB-500 LB.
(O) G.P. BOMB-1000 LB.
(P) S.A.P. BOMB-1000 LB.
(Q) LOW DRAG (GP) BOMB-1000 LB.
(R) G.P. BOMB-2000 LB.
(S) LIGHT CASE BOMB-4000 LB.

3.119

Figure 9C5.—1000-pound low-drag bomb (GP).

Semi-armor-piercing (SAP) bombs. These bombs have a medium heavy case and normally are tail-fuzed. However, the solid-metal nose-plug can be replaced with a nose fuze, when it is tactically necessary. Thirty percent of the complete weight of the bomb is explosive. Semi-armor-piercing bombs sometimes are used as substitutes for general purpose bombs.

General purpose (GP) bombs. These bombs are used in the majority of bombing operations. The case is relatively light. Approximately 50 percent of the complete weight of the bomb is explosive. General purpose bombs may use both nose and tail fuzes.

Low-drag general purpose (GPLD). Bomb development has progressed rapidly during recent years. The majority of new bomb types are of the low-drag general purpose (GPLD) variety designed specifically for use with high speed aircraft (speeds up to mach 2.5). An example is Snakeye (fig. 9C6) which has the low-drag configuration and is designed for low level attack. Snakeye can be accurately delivered in all delivery modes against a variety of targets. Detailed information concerning this bomb as well as the many other new developments is classified, however, and thus cannot be covered in this volume.

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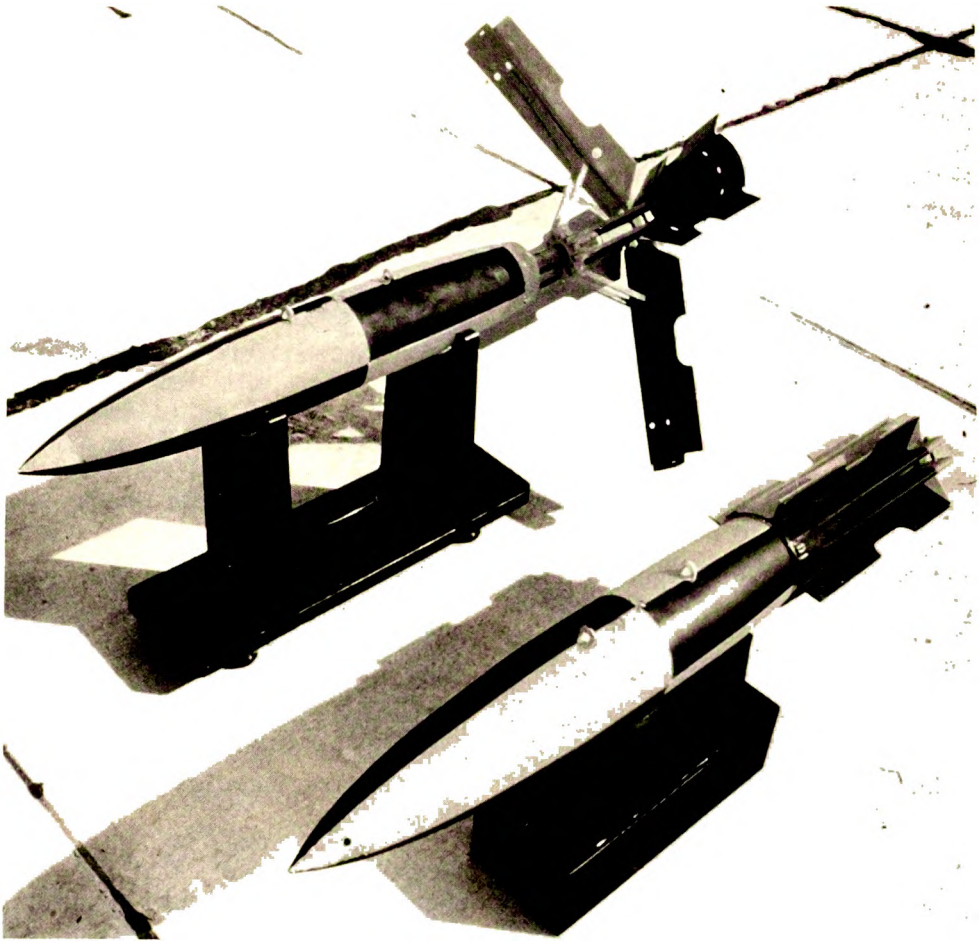

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Figure 9C6.—Snakeye.

Fragmentation (Frag) bombs (fig. 9C7.) Fragmentation bombs cause destruction primarily by the bursting of their cases. The cases of these bombs are so constructed that upon detonation, they break up into hundreds of fragments which will destroy personnel, animals, and light material targets such as motor transports and aircraft on the ground. Fragmentation bombs are fused to explode before penetration.

A fragmentation bomb usually consists of a thin steel cylinder around which is wound a heavy helical steel band. When the filler explodes, this coil of steel splinters.

Aircraft depth (AD) bombs. The aircraft depth bomb is used primarily against underwater targets. It has a secondary use as a demolition bomb. Because of its light case, approximately 70 percent of its complete weight is explosive. A flat nose prevents ricochet when dropped into the water. The depth bomb is fuzed with a hydrostatic tail fuze which functions at a predetermined depth rather than on impact. A nose fuze may be substituted for the hydrostatic tail fuze when used as a demolition bomb.

Practice (O) and miniature practice (MP) bombs. These types of bomb are used for target practice. There is a wide range of types and weights in order to simulate all types of service bombs. Some practice bombs have a fuze and a spotting charge; others are completely inert. Practice bombs generally are loaded with sand or water; some are fabricated to a desired weight.

Fire (incendiary) bombs. There are two types of incendiary bombs. Incendiary bombs designed

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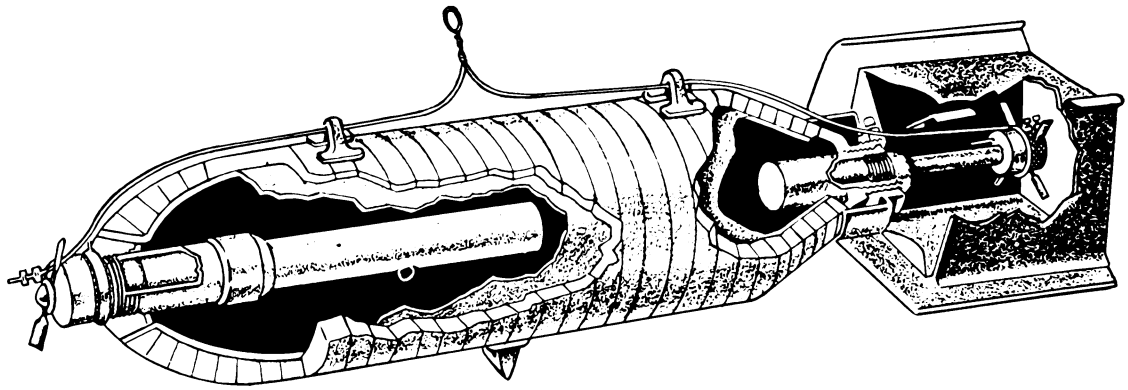

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Figure 9C7.—Sectional view 260-pound. Fragmentation Bomb.

for use against light flammable targets contain a mixture of oil or gasoline with a composition called napalm. The mixture, called oil gel, is a sticky combustible material something like rubber cement. The incendiary filler is ignited and scattered around by a small black powder bursting charge when the bomb strikes. It sticks to the sides of buildings, tents, and the like, and sets them afire. Because of the scattering action of this type of bomb, it is called a scatter incendiary.

Well adapted through it is for attacking targets such as light frame structures, the scatter-type incendiary is not very effective against substantial buildings. To ignite such targets, a more intense heat is required, and can be supplied by the intensive incendiary bomb. This is a small bomb (on the order of 4 pounds) which burns for several minutes at temperatures in the neighborhood of the melting point of steel, so that anything near it which can possibly burn will be set afire.

The bomb filling is thermate or thermite—a mixture of aluminum powder and iron oxide which, when it burns, produces temperatures high enough to melt iron. The case is of magnesium—a metal that burns so easily and intensely that it is used in photographic flashbulbs.

9C8. BOMB FUZES

A bomb fuze in analogous to a gun projectile fuze. It is a device used to cause the bomb to explode at the time and under the circumstances desired, and to prevent the bomb's explosion at other times. This is accomplished by the use of sensitive explosive elements and the required mechanical or electrical devices.

To achieve different types of control for different types and sizes of bombs, many varieties of fuzes are required. These different varieties of fuzes are installed in different locations in the bombs.

Normally, fuzes are in a safe or unarmed condition to ensure that they do not detonate prematurely. In unarmed condition a fuze cannot cause the bomb to explode. A fuze is ready to detonate the bomb when all parts are set so that the fuze can operate. This is the armed condition. This usually is accomplished by either the ejection of an arming pin, the rotation of an arming vane, the closing of a circuit, etc.

Five types of fuzes are used to control detonation:

When the bomb strikes, a fuze ignites the thermate. The thermate filler and the magnesium body burn for 10 minutes or more at a temperature of nearly 2500°F.

In each cluster of these incendiary bombs, some bombs are loaded with an explosive charge which goes off after the bomb has burned for 1 to 4 minutes. This charge, which is big enough to kill anyone nearby, is intended to discourage people from trying to pick up the burning bombs with long-handled shovels.

Impact fuzes. There are two kinds of impact fuzes—mechanical and electrical. The mechanical impact fuze is actuated by a firing pin being driven into a primer by direct contact (nose fuzes) or by means of inertia (tail and

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multiposition fuzes). The electrical impact fuze is actuated by electrical energy passing through an electric detonator. The action may be instantaneous, whereby the fuze acts to explode the bomb immediately; or delayed, whereby, the fuze will not explode the bomb until a definite time has elapsed. This delay allows the bomb to penetrate the target before exploding. It also permits a low-flying plane to clear the area after dropping a bomb. Electric fuzes are being used in almost all new bomb developments.

Time fuzes. This type fuze explodes the bomb at a predetermined time after release, by mechanical or chemical action.

Hydrostatic fuzes. Hydrostatic fuzes are water pressure activated fuzes which are used in depth bombs or in GP bombs when used against underwater targets. Water, entering the ports in the fuze body, expands a bellows. As pressure increases with water depth, the bellows extends, forcing a piston downward.

Antidisturbance fuzes. Antidisturbance fuzes are ready to function a few seconds after impact. The mechanism is extremely sensitive, and any movement after impact will cause the fuze to be detonated.

Proximity fuzes. Proximity (or VT) fuzes contain miniature combination radio transmitters and receivers and are always located in the nose. They detonate before impact when any substantial object is detected a predetermined distance away.

Installation of fuzes. Fuzes must suit the function or purpose of the bomb in which they are to be installed. They are designed for installation in the nose, in the tail, or in the side of a bomb.

Fuzes usually fit the small-size bombs of a series, without any additional auxiliary parts. As the bombs increase in size, standardized fuze seat liners and adapter-boosters are needed to compensate for increased diameter and depth of the fuze well.

Nose and tail fuze seats are machined in the bomb casing. Their dimensions (thread size and depth of seat) are standardized for maximum flexibility of use.

Components used in fuzing larger bombs are described below.

The fuze seat liner is a metal cup assembled inside the nose of the bomb to keep the cavity clear for installing the fuze. Tail adapter-boosters serve the same purpose as fuze seat liners for tail fuzing.

The auxiliary booster consists of a column of tetryl pellets or other sensitive explosive in a suitable container. Its function is to relay and amplify the detonation wave from the booster to ensure proper detonation of the main charge.

The adapter-booster is a bushing threaded on both the inside and outside and is used for the assembly of fuzes to larger bomb bodies. It includes an explosive booster charge.

Fuze delays and functioning times. Often, even with impact fuzes, delay is desirable in fuze functioning to make the bomb more effective. This is important in bombs designed to penetrate armor, for instance. This delaying action is incorporated into many fuzes by putting a delay element into the firing train, next to the primer. The delay element is usually a pellet of tightly packed black powder which is ignited by the explosion of the primer. It takes a definite time (depending on the fuze, from 0.01 second to 0.1 second) to burn through.

A second primer, the relay, next to the delay element, explodes when the delay has burned through it. The relay sets off the detonator and the remainder of the explosive train.

The amount of delay in the firing of a fuze is its functioning time. Functioning time can be adjusted in some fuzes, or the delay can be cut out of the explosive train for instantaneous firing.

The primer and detonator in tail fuzes equipped for delay firing are mounted in a separate piece—the primer-det—screwed into the base of the fuze. The primer-det is made with several different delay times, from zero (instantaneous functioning) to 0.1 second.

Arming of bomb fuzes. When a bomb fuze is unarmed (safe), it cannot function. In some fuzes, a pin through the striker (equivalent to a firing pin) keeps it safe; in others, a "safety block" of metal under the striker head, or a screw securing it to the fuze body, performs this function. In "detonator-safe" fuzes, the detonator or primer is out of line with the firing pin when the fuze is unarmed. Some fuzes use a combination of methods.

Bomb fuzes are usually armed mechanically by the rotation of miniature air screws called arming vanes. These are turned by the passage of air as the bomb falls. The function of the arming wire, when used with vane-armed fuzes, is to prevent the vanes from rotating in the plane's slipstream and arming the bombs before release.

Physically, the arming wire is a length of brass or bronze wire with a flat eyelet at one

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end. Usually two wires—one for the nose fuze and one for the tail—are attached to the same eyelet. The wires are threaded through the fuzes so that they foul the arming vanes (fig. 9C2). Safety clips (also called Fahnestock clips), slid over the wire next to the fuze, keep the wire from slipping out from between the vanes. The eyelet end of the arming wire is engaged by a retainer on the bomb rack or shackle from which the bomb is suspended. The retainer's functioning is controlled by the bombardier's selector handle. If the selector handle is set on "Safe" when the bomb is dropped, the retainer releases the arming wire with the bomb, so that the vanes cannot rotate and the fuze remains unarmed. If the handle is set on "Arm," the retainer holds the arming wire firmly; the bomb drops without the wire, the vanes turn freely, and by the time the bomb is safely distant from the aircraft, the fuze is fully armed.

Some bomb racks and shackles have several arming wire hooks on them. Thus it is possible to arm one fuze and not the other. This is called selective arming.

Bomb fuze arming may be either direct or delayed. In direct arming, the fuze becomes armed or ready to function immediately on ejection or removal of the arming pin, or safety blocks, or when a part is unscrewed by torotation of the arming vane. In delayed arming, ejection of the arming pin initiates a powder train or clockwork mechanism which arms the fuze after a set time. Or the arming vane's rotation may be conveyed to the arming stem by a reduction gear train which delays its disengagement.

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CHAPTER 10
UNDERWATER ORDNANCE

Underwater Ordnance is the science of destroying or disabling an enemy ship by means of an underwater explosion. Weapons of underwater warfare include the torpedo, the mine, the depth charge, the depth bomb, hedgehogs, rockets, and some others. Of these the torpedo is the most important.

Underwater weapons such as the conventional depth charge and hedgehog are discussed in chapter 11. Because nearly all of these weapons are obsolescent and are rapidly becoming obsolete, they will not be given further coverage.

The Navy's latest underwater weapons such as Asroc, Subroc, Astor, and Dash are also discussed as far as security permits in chapter 11. Therefore a basic and rather detailed discussion of the torpedo and mine will be found in this chapter.

A. Introduction to Torpedoes

10A1. GENERAL TORPEDO CHARACTERISTICS.

A torpedo is a self-propelled underwater weapon that carries a high-explosive charge. The mine, the depth charge, and the depth bomb are all underwater weapons. But those three, (as mentioned above) after they enter the water, merely sink under their own weight. The torpedo is the only underwater weapon equipped with a power plant that takes it to the enemy ship. (Some weapons combine some of the characteristics of a mine with those of a torpedo).

Because the torpedo warhead explodes under water, it can do more damage than a projectile with the same weight of explosive. When a projectile explodes, a part of its force is absorbed by the surrounding air. But water is practically incompressible. When the torpedo warhead explodes, the water transfers the force of the explosive shock wave to the hull of the target ship.

The torpedo makes it possible for small ships to carry heavy armament, but of course it cannot make a small ship the equal of a large one in combat. A torpedo moves slowly compared to a projectile or rockets, and its effective range is much shorter.

10A2. DEVELOPMENT OF THE TORPEDO

During the American Revolution, Dr. David Bushnell got the idea that an explosion in the water, beside the target's hull, would do more damage than the same explosion above the water line. To test his idea, he made up a number of powder kegs (fig. 10A1) and launched them in the Delaware river to float down on the British Fleet. But because he guessed wrong about the tide, his powder keys did no damage. However, his floating powder key is the ancestor of the modern torpedo and mine. All the improvements that make our present torpedoes and mines more effective than floating powder kegs were added gradually.

Credit for the first self-propelled torpedo goes to a Captain Lupius, of the Austrian Navy. Lupius worked out his idea during the American Civil War. But Lupius didn't have the mechanical know-how to actually build the torpedo.

In 1864 he took his plans to Robert Whitehead, a British engineer. After two years of work, Whitehead produced a short torpedo, 14 inches in diameter, with 18 pounds of dynamite in its warhead. It was powered by a piston engine operating on compressed air at 700 psi. Whitehead's first torpedo ran at 6 knots, for

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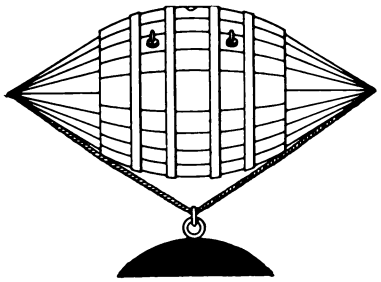

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Figure 10A1.—Bushnell's keg mine.

about 100 yards. On some of its tests it ran along the surface; on others it dived to the bottom.

Whitehead invented many of the devices that are found in modern torpedoes. For example, the air system of the Whitehead torpedo was controlled by a stop valve, a charging valve, a starting valve, and a reducing valve. To keep his torpedo running at the proper depth, Whitehead invented a depth mechanism containing a hydrostatic diaphragm and pendulum. (Air-steam torpedoes have all these parts.) To keep his torpedo on course Whitehead invented a servomotor to operate the steering rudders. Whitehead developed the idea of replacing the warhead with an exercise head for practice shots.

While Whitehead was improving his torpedo, other inventors were busy, too. Most of these experimental torpedoes were abandoned shortly after they were tested. Air-steam torpedoes are based on Whitehead's ideas. But three big improvements on Whitehead's basic invention have been made:

(1) substituting turbines for the piston engine,
(2) adding fuel to superheat the compressed air, and
(3) adding a gyroscope to control the steering engine.

10A3. REQUIREMENTS OF A TORPEDO

As previously stated, a torpedo is a self-propelled weapon. Its principal requirements are, therefore, a charge of explosive and a power plant. As a practical weapon, a torpedo must have a number of other features, including:

1. A shell, or housing, strong enough to support the explosive charge, power plant, and related mechanisms, and strong enough to withstand the shock of launching.
2. A source of energy for the power plant, and for the torpedo control mechanisms.
3. An exploder that will detonate the explosive charge when the torpedo reaches its target, but which will remain inoperable while the torpedo is close to the firing ship.
4. Control mechanisms that hold the torpedo on a preset course, at a preset depth.
5. One or more propellers to drive the torpedo through the water.
6. Tail vanes and rudders, to control course and depth.
7. Homing torpedoes require, in addition, a homing device which will enable the torpedo first to search for the target, then to sense the target as it approaches, and finally to steer itself on a collision course with the target. At present, homing devices function on acoustic principles.

10A4. TYPES OF TORPEDOES

All torpedoes are similar in general exterior appearance. They differ considerably, however, in function and capabilities. Torpedoes may be classified in several ways:

1. By their power plants (air-steam, chemical, or electric). The power plant of an air-steam torpedo consists of a pair of turbines and a gear-reduction engine. In "conventional" air-steam torpedoes (now mostly obsolete), energy is provided by compressed air and burning alcohol. In the chemical type, (navol) the energy source is alcohol reacting with a concentrated solution of hydrogen peroxide. Electric torpedoes are powered, of course, by electric motors; the energy source may be a storage battery, or a seawater-activated battery.
2. By the craft from which they are launched (destroyer, submarine, or aircraft).
3. By speed and range.
4. By the type of exploder used. The impact exploder operates only when the torpedo actually strikes its target. The influence exploder (which will not be detailed in this text) operates when the torpedo passes near its target.
5. By the type of control mechanism. In older "conventional" torpedoes, the control mechanism in the torpedo holds the torpedo on a previously calculated collision course with the target, or on a preset "pattern-running" course if it misses. The homing torpedo can steer

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itself toward its target and, if necessary, chase it.

10A5. FUNCTIONAL ELEMENTS OF A TORPEDO

As you will note in later parts of this chapter, torpedoes are among the most rapidly evolving weapons in the fleet. However, some aspects of torpedoes remain fairly constant, particularly their exterior shape and functional elements (and even the arrangements of the elements in the torpedo structure). Let us briefly consider these aspects which apply to all torpedoes.

EXTERIOR SHAPE. Ever since the first practical automotive torpedo was developed by Whitehead the exterior shape has remained almost the same. Most torpedoes are elongated cylinders with relatively blunt noses and tapering tails. The standard diameter for torpedoes are 10, 12.75, 19 or 21 inches. Most torpedo tubes consist of 21" diameter barrels and with the proper equipment can accommodate torpedoes of any diameter. The nose may be either ogival, spherical, or flat. The tapering tail mounts fins with vertical rudders and horizontal stabilizers (the latter corresponding to elevators in an aircraft) as well as either one or two screws. If there are two screws, they rotate in opposite directions (counterrotation), so that the reaction of a single screw will not cause the torpedo body to rotate. If a torpedo has a single screw, either its tail fins are canted or its body is fitted with canted longitudinal ribs or ridges to produce a torque opposing that of the single screw as the torpedo passes through the water.

TORPEDO ELEMENTS. A torpedo is generally constructed in four sections, each of which is concerned with a specific function. These sections are the head, the midship section, the afterbody, and the tail (fig. 10A2). Most of the new homing torpedoes however have only three sections: the afterbody and tail section are usually combined.

The head may be either a warhead or an exercise head. The warhead contains the main charge and its exploding device, as well as (in a homing or influence-fired torpedo) the acoustic and magnetic sensing elements used in steering the torpedo and firing the charge. For target practice, an exercise head which brings the torpedo to the surface after firing is used.

The midship section (which may have different names in different types of torpedo) in general houses energy-storing or energy-supplying devices, such as compressed air flasks, batteries, fuel and oxidizer tanks, and the like. It may also contain some controlling devices such as valves or some guidance equipment. The midship section may actually be constructed as two parts. In air-steam-powered torpedoes, it is called the air flask section; in some electric-powered torpedoes, it is called the battery compartment.

The afterbody contains the propulsion engines and gearing and guidance equipment.

The tail includes the fins and control surfaces, the exhaust system (if any), and the screws that propel the torpedo. All standard torpedoes now in active service use screw propulsion, though jet propulsion has been used experimentally.

Torpedoes may be fitted with other accessory parts required for special launching methods. Thus torpedoes modified for rocket or missile propulsion (such as those used with Asroc) may be fitted with parachutes and buffers to reduce shock when they enter the water, and with special hardware for attachment of airframes or suspension from aircraft.

10A6. LAUNCHING METHODS.

There are four principal ways to launch a torpedo—by firing it from a tube, by dropping

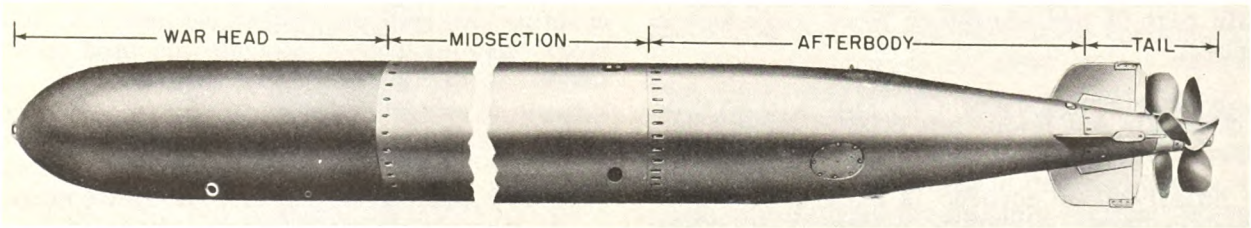

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Figure 10A2.—Typical torpedo features.

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it from a rack, by propelling it part of the way to its target as a rocket payload, or by letting it swim out.

Aircraft drop torpedoes from launching racks; usually, an aircraft carries only a single torpedo. A helicopter can carry one or two torpedoes for A/S work.

The Navy's older destroyers as well as the newer FRAM destroyers, DDGs, and DLGs carry torpedoes in the 3-barrel Mk 32 launcher. (Fig. 10D2.)

The tube is usually carried amidships. It can be trained through a wide arc, so that torpedoes may be fired over the side of the ship. Compressed air expels the torpedoes from the tube with enough force to clear the firing ship. These 3-barrel tubes have all but superseded an older 5-barrel tubes that used black-powder impulse charges to expel the torpedo.

Some destroyer escorts are fitted with fixed, nontrainable tubes—usually four of them. The tubes are located above the main deck with their muzzles extending through the sides of the deck house.

Submarines fire torpedoes from fixed, below-water tubes.

On firing, the torpedoes are expelled from the tubes by hydraulic ejection or compressed air or they swim out under their own power. Spare torpedoes are carried in ready racks near the tubes. A submarine of this type on war patrol will usually put to sea with a load of 28 torpedoes aboard. Data on number of tubes and torpedoes in later types of submarine cannot be published in an unclassified textbook.

10A7. APPLICATIONS

The torpedo is an important weapon of all modern destroyers. Torpedoes are the principal armament of submarines, and under certain conditions, of aircraft. Torpedoes also constitute the payload of more advanced A/S weapons such as Asroc and Dash.

The tactical use of torpedoes has changed tremendously over the past few years. Their use in surface engagements is likely to be much less frequent than it was before. The outcome of a battle will most likely be decided before the enemy is within torpedo range.

On the other hand, torpedoes have become very important in ASW. In this application they may be launched from air, surface, or undersea craft to attack a submerged target even when the target's exact position and depth are unknown.

B. Air-Steam Torpedoes

10B1. INTRODUCTION

Although the air-steam torpedo does not represent the most advanced state in the art of torpedo design, it still is used to a limited extent throughout the fleet. The air-steam torpedo is also more suitable for a detailed discussion than are more advanced types because of security reasons. We shall therefore take up the air-steam torpedo in some detail as the main part of our survey of Navy torpedoes in general.

10B2. CONSTRUCTION OF THE AIR-STEAM TORPEDO

An air-steam torpedo is built in five sections—the head, air flask, midship, afterbody, and tail. Since the midship section is permanently joined to the air flask section (although separate in function), it is usually not counted as a separate section. Figure 10B1 is a cutaway view of a Mk 15 type air-steam torpedo, showing the principal contents of the various sections.

10B3. HEAD SECTION

The head section may be either a warhead, an exercise head, or a war-exercise head.

The warhead (fig. 10B2) is almost entirely filled with high explosive (usually HBX) and contains the exploder which detonates it. Most types also have lead weights mounted on the inside of the shell. These weights keep the torpedo in an upright position.

The exploder serves two main functions:

1. It detonates the main charge of high explosive when the torpedo reaches its target.
2. It prevents accidental damage to the firing ship by remaining inoperable—so that the main charge can't explode—until after the torpedo has completed the first part of its run.

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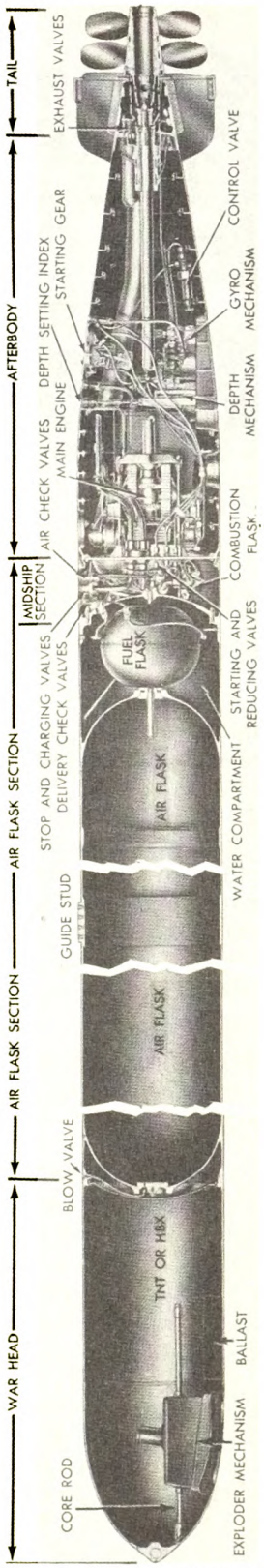

Figure 10B1.—Cutaway view. Torpedo Mk 15 type. 3.126

The exploder may be one of two types—"contact" or "influence". The contact exploder explodes the main charge only when the torpedo strikes a solid object. The influence exploder contains an electronic mechanism that operates when the torpedo passes UNDER a large mass of iron or steel. The torpedo doesn't have to actually strike the target ship. The torpedo thus can be aimed so that it will explode UNDER the target keel, where it will do more damage.

While the torpedo is aboard the firing ship, and during the first part of its run, the exploder is kept inoperable. Even if its detonator should explode accidentally, it wouldn't detonate the main charge. However, as the torpedo runs through the water and reaches its enabling range or depth, the exploder mechanism realigns itself, making detonation of the main charge possible as soon as the firing circuit is closed.

For a test shot, or for firing practice, an exercise head (fig. 10B3) instead of a warhead is used. The exercise head, of course, contains no explosive charge or exploder mechanism. For an exercise shot, the head section is filled with water or a chemical solution, so that it weighs approximately the same as a warhead. At the end of the exercise run, an air-releasing mechanism in the exercise head opens (blows). Compressed air enters the head and forces the water out through the water discharge valve in the bottom of the shell. When the head is empty, it gives the torpedo enough positive buoyancy so that it can float until recovered.

In the top of the exercise head is a headlight, a depth and roll recorder, or a torch pot. These devices help in locating the torpedo after an exercise shot, and record depth and roll of the torpedo throughout the entire run.

The war-exercise head is much like the exercise head except that it has an exploder cavity. It is used to test the action of the torpedo exploder. (Use is limited to test ranges.)

10B4. AIR FLASK SECTION

As can be seen (fig. 10B4), the air flask section is the longest part of the torpedo. The air flask itself takes up most of this section. The flask carries the torpedo's air supply at a pressure of 2800 psi. Abaft the air flask is the water compartment, and inside the water compartment is a bulkhead that divides the air flask section from the midship section. The fuel compartment is in the center of the water compartment attached with brackets to the water compartment bulkhead.

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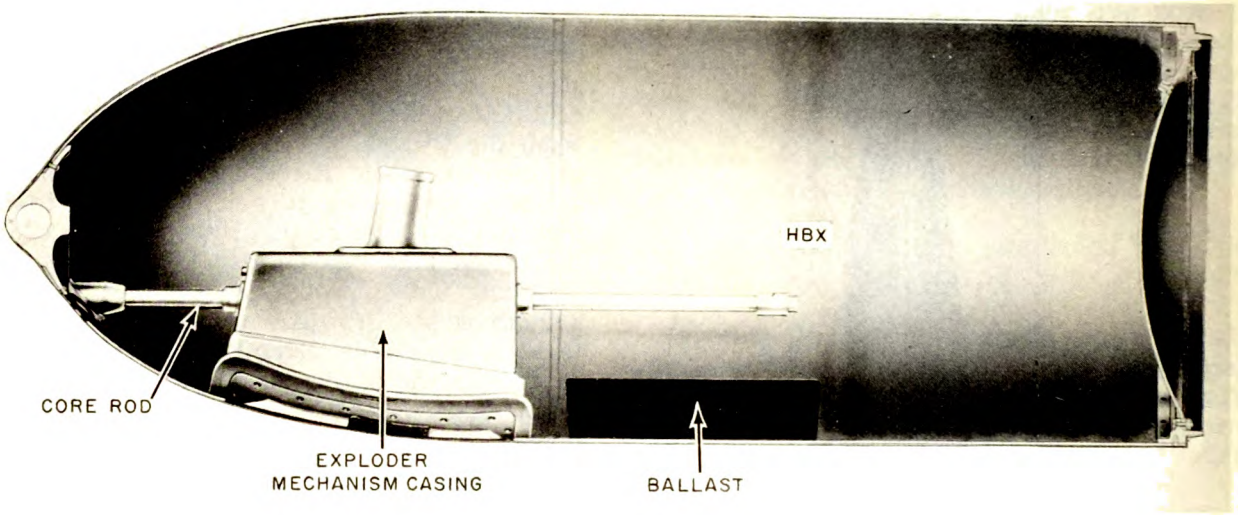

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Figure 10B2.—Warhead.

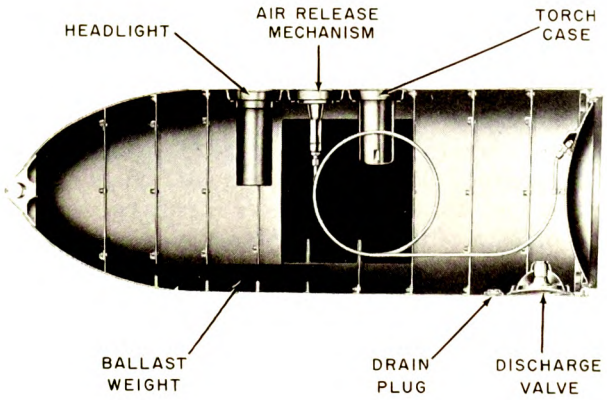

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Figure 10B3.—Exercise head.

10B5. MIDSHIP SECTION

Inside the midship section (fig. 10B4) are a number of pipes that carry air, fuel, and water from the air flask section to the superheating system in the afterbody. A number of valves are mounted on the shell of the midship section. They are—

1. The STOP and CHARGING VALVES. The stop valve controls the air in the air flask. By closing the stop valve the air flask can be shut off from the rest of the air system. The charging valve provides a means for charging the air flask.

2. The FUEL and WATER STRAINERS and CHECK VALVES. The strainers pick up any foreign matter in the water and fuel that could clog the fuel and water sprays. The check valves prevent fuel and water leakage over to the combustion flask. Any pressure that may build up in fuel and water compartments is vented to the afterbody.

3. The AIR CHECK VALVES. These valves separate the fuel and water compartment from each other and provide a means of putting air pressure into the top of fuel and water compartments at the same time and same pressure.

10B6. AFTERBODY

The afterbody (fig. 10B5) is the torpedo's engineroom and control officer. The propelling and controlling mechanisms. These start the torpedo, generate and apply the power necessary to drive it from the time it is launched until it completes its run, determine the torpedo's vertical and horizontal courses, and maintain it on those courses throughout its run.

The afterbody is sealed at its forward end by the turbine bulkhead. Several important parts of the torpedo are mounted on or aft of this bulkhead. They include:

1. Reducing valve. The air in the air flask is too highly compressed to go directly into the combustion flask. The reducing valve is used to bring the air pressure down to the proper level.

2. Combustion flask. In this flask, the burning of compressed air and fuel occurs. Simultaneously, water enters the flask and is converted into steam.

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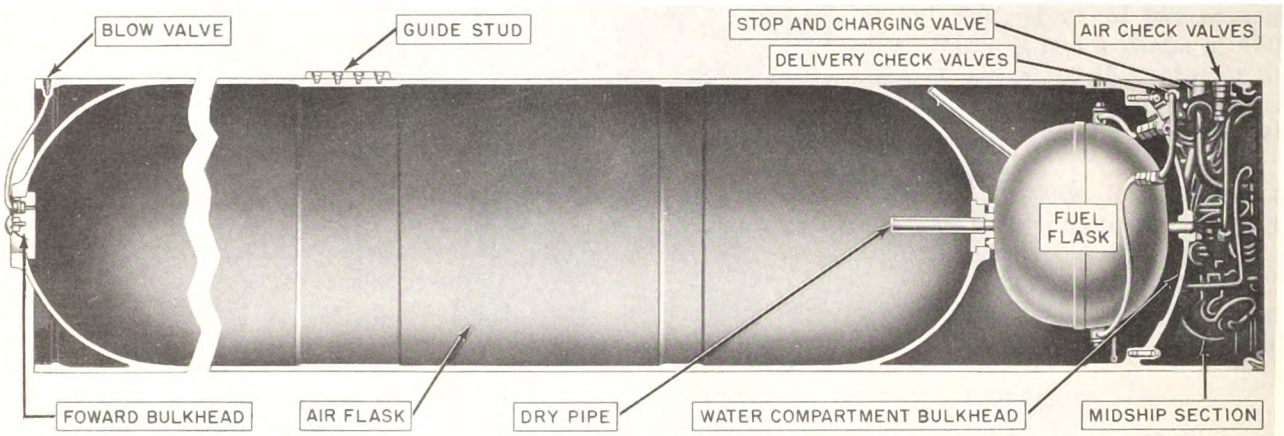

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Figure 10B4.—Air flask and midship section.

3. Speed change mechanism. Most torpedoes are designed to run at just one speed. But in two types—Mk 14 Mod 3A and Mk 15 Mod 3—the speed is adjustable. (The Mk 14 Mod 3A has two speeds; the Mk 15 Mod 3 has three.) In these torpedoes, the speed change mechanism is mounted on the forward face of the turbine bulkhead. It controls the speed of the torpedo by controlling the flow of hot gases from the combustion flask to the turbines. (In the Mk 15 Mod 3, it also shifts the gears in the main engine.)

4. Turbines. The two turbines are mounted on the after side of the turbine bulkhead. The hot combustion gases flowing from the combustion flask strike the turbine blades, thus spinning the turbine.

5. Main engine. The main engine consists of a gear system that transfers the turning force of the turbines to the two propeller shafts. One of these shafts is hollow, and the other turns inside it. The two shafts turn in opposite directions, thus helping to eliminate torque which would result if only one propeller were used.

6. Control mechanisms. The two control mechanisms—the steering mechanism and the depth mechanism—keep the torpedo on course and at the proper depth during its run. The steering mechanism turns the torpedo to its preset course, and keeps it there. If the torpedo wanders off course to left or right, the steering mechanism moves the vertical steeering rudders to correct the error. The depth mechanism brings the torpedo to its preset depth and keeps it there. If it starts to rise too high in the water, or sink too low, the depth mechanism moves the horizontal rudders to bring the torpedo back to its proper depth.

The heart of the steering mechanism is the gyro. During the run, the axis of the spinning gyro remains rigid in space; that is, it points constantly in the same direction. If the torpedo turns off its set course, the gyro axis will still point in its original direction. That means that when the torpedo turns off course, the gyro will be in a different position relative to the rest of the torpedo. The steering mechanism detects this difference, and sends correcting orders to the steering engine. The steering engine then turns the steering rudders, to bring the torpedo back on course.

7. Exhaust system. The exhaust system carries the spent gases from the turbines, through exhaust valves in the after bulkhead, out through holes in the forward and after propeller sleeves to the sea.

10B7. TAIL

Mounted on the outside of the tail cone are four fins, or vanes, which help to control the path of the torpedo during its run. Located on the after edge of the vertical fins are the two steering rudders, while both of the horizontal fins are on the after edge of the two depth rudders.

The torpedo propellers are mounted on the hollow sleeves at the end of the tail cone.

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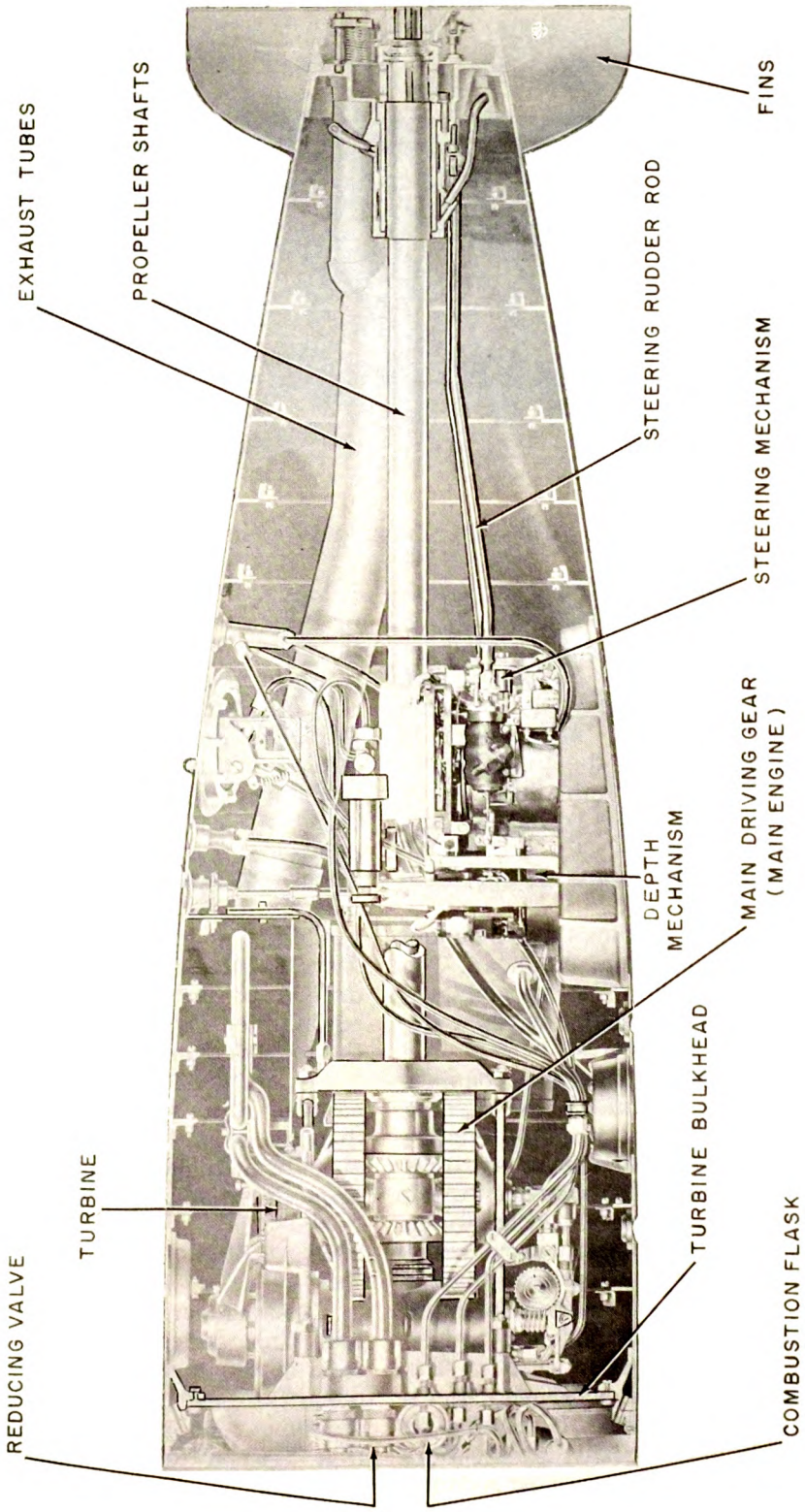

Figure 10B5.—Afterbody

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10B8. TORPEDO OPERATION

The following is a brief explanation of an air-stream torpedo in operation:

1. On the upper part of the torpedo's afterbody is a starting lever. The launching mechanism operates the starting lever at the instant the torpedo is launched. When the torpedo is fired from a tube, the tripping latch strikes the torpedo starting lever and throws it aft, thus starting the torpedo mechanism.
2. The starting lever operates the starting mechanism which in turn allows the starting valve to open.
3. High pressure air from the air flask flows through the starting valve to the gyro-spinning mechanism, which spins the gyro and brings it up to full speed (20,000 rpm).
4. High pressure air from the flask goes through the starting valve to the reducing valve. Reduced pressure from the reducing valve serves some of the following functions:
   a. Reduced-pressure air flows directly into the combustion flask.
   b. Reduced-pressure air enters the fuel and water compartments, and forces fuel and water into the combustion flask.
   c. Reduced-pressure air fires the igniter, which ignites the mixture of compressed air and fuel in the combustion flask.
5. Hot gases from the combustion flask spin the turbine.
6. The turbine, connected with the main engine and the propeller shafts, spins the two propellers.
7. Low pressure air flows to the gyro, to keep it spinning throughout the torpedo run.
8. Reduced-pressure air flows to the depth and steering engines, and provides the energy which allows them to operate the steering rudders and depth rudders.

10B9. AIR-STEAM TORPEDOES IN ACTIVE SERVICE

Most air-steam torpedoes have been declared obsolete throughout the fleet in favor of the newer homing torpedoes. The two types of air-steam torpedoes listed below are now obsolescent and probably will also be declared obsolete in the very near future. (By "obsolescent" we mean that these torpedoes are used for target practice and exercise, and new units are being issued from stock, but no more are being manufactured.)

The Mk 14 Mod 3A is designed to be fired from submarines. Its length is about 20-1/2 feet. It can be set for either of two speeds. At the high speed setting it has a range of 4500 yards, at an average speed of 46 knots. At the low speed setting its range is 9000 yards, and its average speed is 32 knots. It carries 600 pounds of high explosive.

The Mk 15 Mod 3 torpedo is designed to be launched from the deck tubes of DEs. It is 24 feet long, and carries about 800 pounds of high explosive. It has three speeds: 26-1/2 knots (range 15,000 yards); 33-1/2 knots (range 10,000 yards); and 45 knots (range 6000 yards).

10B10. MK 16 TYPE TORPEDO

Mk 16 designates a family of single-speed 21-inch by 21-1/2 foot submarine torpedoes. All of them are air-steam torpedoes in which hydrogen peroxide (NAVOL), instead of compressed air, supplies the oxygen required for combustion of the fuel. This use of NAVOL rather than air allows the Mk 16 torpedo to carry a full load of explosive and to have greater high-speed range, while not exceeding normal size.

The head section of this torpedo is similar to that described in the preceding paragraphs. The second or flask section contains a small compressed-air flask, a fuel (alcohol) tank, a water compartment, and a NAVOL tank—the last completely surrounded by the water tank. The main engine, valves, and control devices are located conventionally in the midship section and afterbody.

The source of the oxygen and of part of the water for the combustion cycle of these torpedoes is the NAVOL, which is a solution of hydrogen peroxide (H_2O_2) in water. Hydrogen peroxide, passing through a chamber containing a catalyst, decomposes with evolution of heat, to form water (steam) and oxygen. The oxygen unites with the fuel (alcohol) in the combustion pot, combustion being initiated by a conventional igniter. The resulting hot gases mix with steam and drive the main-engine turbines. Part of the steam comes from the breakdown of the H_2O_2 and part from additional water from the water compartment which is sprayed into the combustion pot to control the temperature.

By using NAVOL, the torpedoes require no air except (1) to force fuel, NAVOL, and water from their storage compartments to the combustion flask, (2) to drive the gyro, and (3) to

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operate the steering controls. As no air is fed to the combustion pot, no nitrogen is present in the exhaust to rise to the surface and leave the customary wake. There is, however, a small amount of nonsoluble gas resulting from the combustion of alcohol. This is forced out of the exhaust, leaving a very small wake that is practically invisible except in flat, calm water.

The main engine is a turbine with reduction gearing, similar in principle to the engine in a Mk 14 or 15 torpedo, but differing considerably in mechanical detail. The turbine axis is horizontal instead of vertical; for this reason this engine is referred to as a "horizontal" or "H" type. Spur gears rather than bevel gears are used for speed reduction.

PATTERN-RUNNING FEATURE. Some mods of the Mk 16 torpedo are capable of "pattern-running." This means that after a straight run of predetermined length on a preset course, the torpedo runs continuously at the same depth in horizontal circles of about 300 yards radius until the end of the run or until it hits a target. A control device in the torpedo called an enabler can be adjusted to vary the length of the straight part of the run (this is called the enabling run), at the end of which the enabler overrides the gyro steering gear and causes the rudders to steer the torpedo in a circle of fixed diameter. The torpedo can be set to circle to the right or to the left, as desired.

The pattern-running feature makes it possible for the torpedo to menace other ships near its target, if it should miss, and is therefore valuable when the torpedo is used in attacks on convoys. The torpedo can be set to run on a straight course only, if desired.

Note that pattern-running is not to be confused with the circular or helical search pattern characteristic of homing torpedoes, as discussed below. Pattern-running torpedoes cannot home on targets. Unlike homing torpedoes, pattern-running torpedo exploders arm early in the enabling run. They initiate the war head charge either on contact with or in proximity to the target.

C. Homing Torpedoes

10C1. INTRODUCTION

The nonhoming torpedoes described in this chapter are designed to follow the course set on their gyro mechanisms, seek the specific depth set on their depth mechanisms, and run in a straight line without deviating (pattern-running torpedoes can also run in circles) until they run out of power. If on a warshot they fail to find a target, they sink.

During World War II, two new features were introduced into torpedo design. The first of these was electric propulsion, resulting in a wakeless torpedo which could not be visually detected from the vessel or target under attack. The second feature introduced completely changed the principles used to guide a torpedo, resulting in a "homing type" torpedo. The homing torpedo (fig. 10C1) is guided by the sound of the vessel being attacked, or by reflected echoes.

10C2. GENERAL DESCRIPTION

A homing torpedo can follow a gyro course, but in general this is done only to get the torpedo to the vicinity of the target. The gyro-controlled run is then called an enabling run, and at the end of it the torpedo exploder is armed, the homing mechanism is activated to search, for the target, and the influence device is set to function. The course taken by the torpedo after the enabling run is called the search pattern. The pattern may be helical, zigzag, circular, etc. It may include a fixed depth zone, or the torpedo may search from bottom to surface and back to bottom again. When the homing mechanism detects a target, the torpedo goes into its third stage of functioning—homing. It chases the target, and when it has come within effective range of the target the influence mechanism operates the exploder to set off the main charge.

For security reasons, no homing torpedo can be discussed in detail here. We can only briefly discuss their principles.

At present, homing torpedoes are acoustic (operated by sound). In general, they are of two types—active and passive.

The active acoustic torpedo is not dependent upon the sound emitted from the target for its

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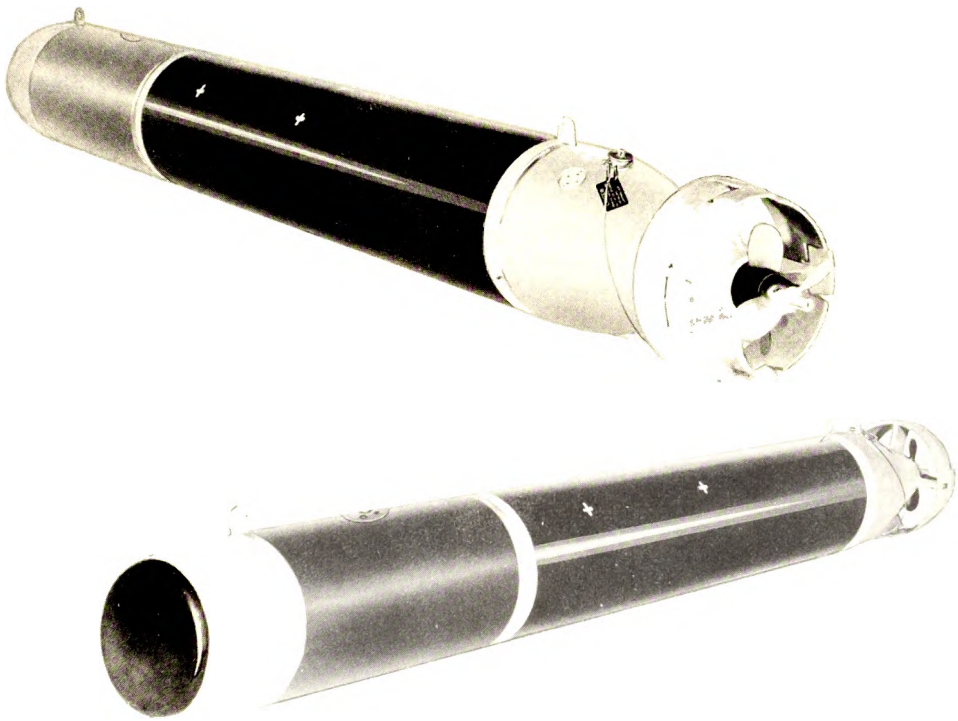

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Figure 10C1.—Electrically driven homing torpedo, Mk 43 Mod 3.

homing information. The torpedo itself generates and transmits the acoustic energy which is essential to its self-directing action. This energy, which has a fixed, controlled frequency and beam width, is reflected by the target in the same manner as "sonar". (See chapter 11). The torpedo is designed to steer on this particular reflected echo, and not on the noises created by the target. The echo, after being received, is converted into electrical signals which control the operation of the rudder and elevator control surfaces, causing the torpedo to home on the target.

The passive acoustic torpedo homes on the target noise emitted from the target. This noise, after being received by the torpedo, is converted into electrical signals which control the operation of the rudder and elevator control surfaces to steer the torpedo in the direction of the noise source.

The passive torpedo is effective only against targets which create or emit noise. It can often be evaded by the use of simple noisemaker type countermeasures which are used purposely to mislead or misdirect it. The target can also reduce its speed, or stop, in order to present a negligible noise source.

The homing torpedo has the same safety devices as the air-steam type described above. Its exploder is armed both mechanically and electrically, and remains safe until the torpedo has traveled a safe distance from the firing ship. The homing mechanism also has an arming feature, so that it remains inoperable (with the torpedo on a gyro course) until the torpedo has traveled through a preset enabling run distance. One or more additional safety features not found in nonhoming torpedoes are present in all homing torpedoes.

Homing torpedoes, almost without exception, are powered by electric motors and batteries. In shape and external appearance they are quite similar to the nonhoming torpedoes already described. Most types are somewhat smaller than air-steam torpedoes, in length, diameter, or both. And several types have a single propeller, rather than two.

Homing torpedoes may be launched with or without torpedo tubes. (All other types described earlier in this chapter are launched

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from tubes.) Many homing torpedoes are electrically set; other are preset (i.e., they are dropped in the vicinity of the target, seek the depth set in advance, and go into the preset search pattern without going through the enabling run stage).

For further discussion on some types of ASW homing torpedoes, see chapter 11.

D. Above-Water Torpedo Tubes

10D1. FUNCTION

Torpedo tubes serve the following purposes:

1. House and protect the torpedo (including heating in cold weather) until the instant of firing.
2. Provide means for setting torpedo gyro angle, running depth, etc., as necessary, up to the instant of firing.
3. Expel the torpedo with sufficient force to clear the firing ship, and with such velocity and direction that it will remain on its firing course until its engine develops enough power for self-propulsion.
4. As expulsion starts, trigger the torpedo so as to start its engine and gyro.

These functions apply to submarine tubes as well as above-water tubes. Since, however, the former must also serve as pressure members of the ship's hull, they incorporate additional features which are beyond the scope of this text.

10D2. TYPE AND LOCATION

Above-water tubes may be classed as trainable or fixed. Functionally their performance is similar, but there are structural differences. Fixed tubes are usually mounted so that their muzzles protrude through a bulkhead or some part of the ship's hull. Trainable tubes require large clear deck areas, and in all ships that carry torpedoes they are mounted topside in some such location as the weather deck. From this location torpedoes can be fired through limited arcs of train on both sides of the ship.

During World War II standard destroyer-type ship armament included one or two quintuple (5-barrel torpedo tubes). A black-powder impulse charge was used to expel the torpedo from the tube in launching. With all tubes loaded, the vessel had 10 torpedoes, plus spares. The torpedoes were all of the conventional air-steam type described earlier in this chapter, normally had impact exploders, and were fired either singly or in salvo against surface targets. Homing torpedoes, then in an early stage of development were not a standard part of destroyer armament, and the use of homing torpedoes by surface craft against submerged submarines was not a standard part of U.S. naval doctrine.

Beginning late in World War II and continuing thereafter, this arrangement of deck-mounted quintuple tubes became obsolescent. One cause of this was the need for increased AA armament; this put a premium on topside deck space. Another was an evolution in doctrine. Direct attack by destroyer-type surface ships against surface targets with conventional air-steam torpedoes was becoming less and less important, while the whole problem of ASW and the use of homing torpedoes against submerged targets became more and more important. (This is more fully discussed in chapter 11.) After World War II destroyer-type ships were fitted with but one quintuple tube, and the conventional torpedo load was reduced from 10 to 5. At the same time, newer designs for destroyer and escort craft had torpedo tubes mounted in above-water locations other than the weather deck. In such locations, the tubes had to be housed and fixed (i.e., nontrainable).

With fixed tubes greater gyro angles must be used in firing than from trainable tubes; and, since torpedoes tend to depart more widely from their predicted courses when fired with large than with small gyro angles, this is a disadvantage. Also, tubes must be carried on both sides of the ship. However, the weight advantage gained by eliminating the training gear, pivots, etc., provides a partial compensation. The interior location permits all tubes to be located in the same compartment of the ship, in which reload torpedoes and quick-reloading gear may also be carried. The newer tube designs use

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compressed air instead of impulse charges to fire the torpedoes, and are usually fitted with electrical accessories necessary for firing electrically set torpedoes, including homing types.

The old type quintuple tubes are still to be found in the fleet. However, they are used very rarely and will therefore not be described here. The torpedo tube Mk 32, described in article 11D4, has all but replaced the quintuple mount.

10D3. ABOVE-WATER FIXED TUBES

Figure 10D1 represents a single-barrel fixed-type nontrainable torpedo tube designed to mount singly or in groups of two or more on each side of a ship. The tubes are mounted athwartship within the superstructure, with muzzles extending through the sides of the deck house. The tubes are constructed of a lightweight aluminum alloy. The torpedoes are ejected by a blast of compressed air. The tubes are suitable for launching only torpedoes having electrically set torpedo controls. The tube was designed to launch 21-inch torpedoes, although adapter rings have been supplied to permit launching a 19-inch diameter torpedo.

10D4. ABOVE-WATER TRAINABLE TUBES

This article takes up only the torpedo tubes Mk 32 which have supplanted most of the old quintuple tubes. There are several versions of the Mk 32 tube. One version is designed to operate with compressed air from the ship's supply; another uses an air bottle and is installed on craft that have no other air supply available. These two are otherwise similar, and are designed to mount on the weather deck.

Each tube assembly consists of three separate and independently operated barrels, mounted on a common training gear (fig. 10D2). The barrels and training gear are equipped with thermostatically controlled electric heating units for cold-weather operation. Each barrel is fired independently, usually by an electric firing circuit. Manual firing is possible for emergencies. The mount can be trained through 190° by manually cranking a worm that engages a worm gear. (A firing cutout mechanism prevents launching of torpedoes in an arc greater than 110°.)

The barrels are arranged in a triangular group, with a pair below surmounted by the third above and between them. Each barrel is fabricated of Fiberglas reinforced plastic. The breech mechanism covers one end of the tube, and the muzzle cover is at the other end. Along the top surface of the tube are two access openings (called the large and small cover assemblies)—one toward the muzzle, the other toward the breech. The openings are used for attaching lanyards to the tube for starting the torpedo and for enabling the exploder to arm. The electrical plug used to set signals into the torpedo before launching is located under the breechward cover.

The muzzle cover is a Fiberglas reinforced plastic assembly with a rubber ring which helps to lock the cover closed. The breech mechanism consists principally of a rubber-lined reinforced

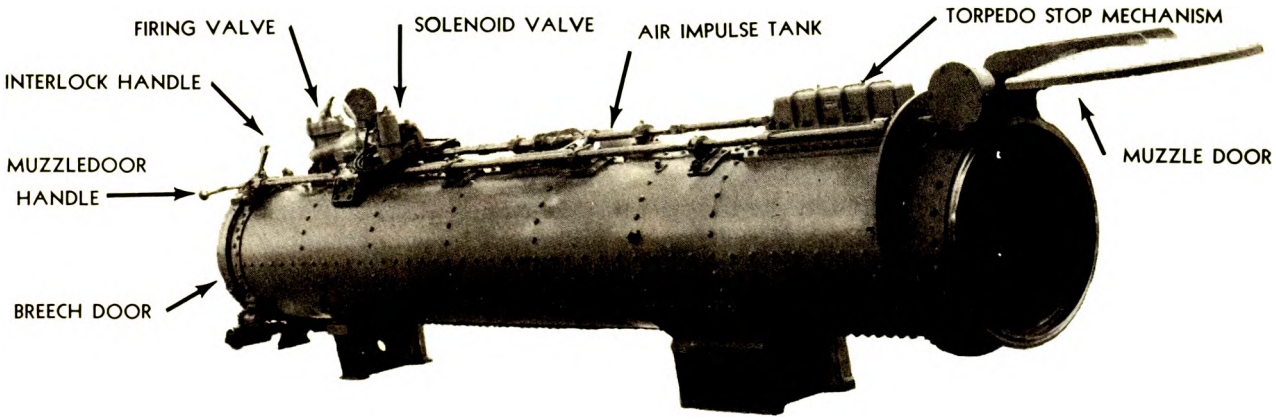

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Figure 10D1.—Fixed above-water torpedo tube.

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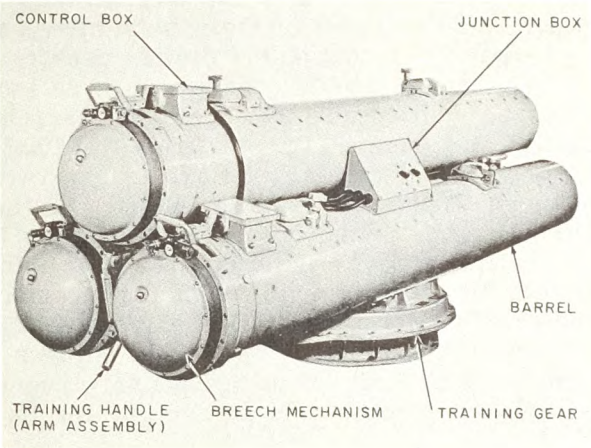

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Figure 10D2.—Torpedo Tube Mk 32 Mod 0, right side, breech end view.

Fiberglas plastic air flask with controls, valves, and fittings on it. It is bolted in place. The tubes are loaded through the breech end. The firing valve in the breech mechanism releases a blast of compressed air into the after end of the tube to eject the torpedo.

A waterproof aluminum control box contains the solenoid-actuated air valve which controls firing. Buttons protruding from the after side of the box provide for either electrical or manual actuation of the valve. A junction box houses the connection between the ship's supply and the electrical heating systems of the barrels and training gear.

Current mods of the Mk 32 launcher are designed to handle the latest homing torpedoes. A nontrainable version of the Torpedo Tube Mk 32 consists of two barrels, one over the other, and is installed in a deckhouse with the muzzles extending through the bulkhead similar to the large tubes described in 10D3.

E. Introduction to Mines

10E1. DEFINITION OF A MINE

A mine, as defined by the Bureau of Naval Weapons, is a thin-cased weapon filled with high explosive and designed to explode under water when struck or closely approached by a ship. (One exception to this general definition is the land mine.) Several types of mines will be discussed in this chapter.

10E2. HISTORY OF MINES

Mine warfare is not new. The Dutch broke the Spanish Blockade of Antwerp in 1585 with what was probably the first floating mine. They called it an "explosive vessel." It was no more than an old ship loaded with gunpowder and ignited by a clockwork-operated flintlock. The British, with the largest fleet in the world at the time, were the first to suffer casualties by the first real mine that was used.

David Bushnell—as previously mentioned—attempted to break the British blockade of the Delaware River at Philadelphia with floating kegs (fig. 10A1) filled with gunpowder and equipped with a contact-firing device.

Robert Fulton also contributed to mine warfare by proving that a ship has little resistance to an underwater explosion. By the time the American Civil War came along, mines were considered a good naval weapon. During this war, 27 Union ships were sunk by mines while only 9 were destroyed by gunfire. Figure 10E1 shows a Confederate mine. At the entrance of Mobile Bay, Admiral Farragut shouted, "Damn the torpedoes—full steam ahead!" But he was referring to what we know as mines, not torpedoes.

Mines were considered only a defensive weapon until the Russo-Japanese War of 1904. The Japanese almost destroyed the Russian fleet by luring them into mined waters. This development opened up a new use for mines, although it was not until World War I that offensive use of mines came into being.

During World War I, the allies bottled up the German U-boats in the North Sea by laying a minefield from Scotland to Norway (fig. 10E2). This allowed the allies to use Atlantic shipping routes in comparative safety. Contrary to popular belief, there were more ships sunk by mines than by torpedoes and gunfire combined during World War I.

After World War I there was a slump in mine warfare development. During the period between the two world wars, new mines were

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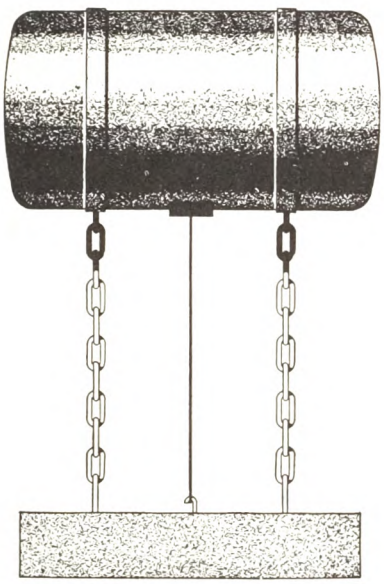

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Figure 10E1.—Confederate harbor mine.

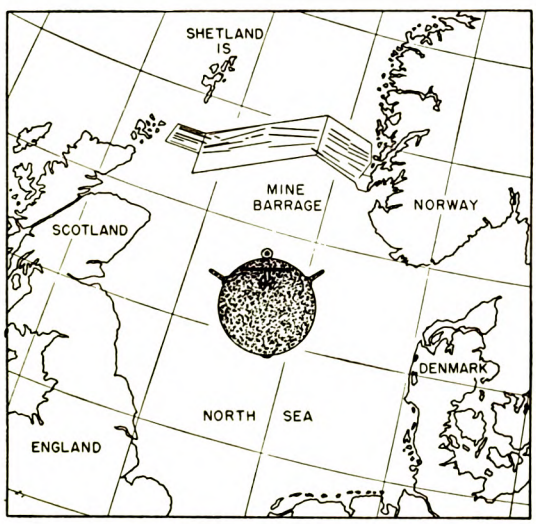

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Figure 10E2.—World War I mine and North Sea Barrage.

designed but not developed to any great extent. At the outbreak of World War II the Germans used a magnetic mine very successfully. Our magnetic mechanisms were so crude that we copied a German device which the British had taken from a captured mine. From 1940 on, mines were developed into very complex weapons, with several ways of planting them and of setting them off.

Again in World War II, during Operation Starvation (the blockading of Japan), (fig. 10G1) mines sank more enemy ships than all other types of weapons combined. This operation was so successful that it almost stopped Japanese shipping completely. A side effect of this was that civilian morale was broken because Japan could not import enough food. This was the United States' largest and most successful use of offensive mining.

Probably for this reason, mine development has not slackened as it did after World War I. This makes it difficult to keep up with the development of new mines and modifications to the old ones. As in the case of torpedoes, a detailed discussion of the various mine marks and mods used today is beyond the scope of this unclassified text.

10E3. MINE CLASSIFICATION

Mines are classified by types in reference to 1) the method of planting, 2) the mine's position in the water, and 3) the method of actuation (firing). These types will be discussed in the following sections.

10E4. HOW MINES ARE PLANTED

By method used in planting, is meant the way mines are put into the water. There are three classifications of mine according to methods of planting: 1) surface-craft laid, 2) submarine-laid, 3) aircraft-laid.

Surface-Craft-Laid Mines

This method of planting mines (fig. 10E3) is used where secrecy is not of prime importance. High speed minelayers are usually used to do the job. A minelayer can carry a large number of mines, and can lay a large minefield in a relatively short time. At the time of writing this text, the Navy has no minelayers in commissioned service. In case of war, however, these ships could be reactivated in a short time.

Submarine-Laid Mines

These mines (fig. 10E4) have an advantage over surface-craft-laid mines in that the mining operation can be accomplished with great secrecy, and at great distances from home ports.

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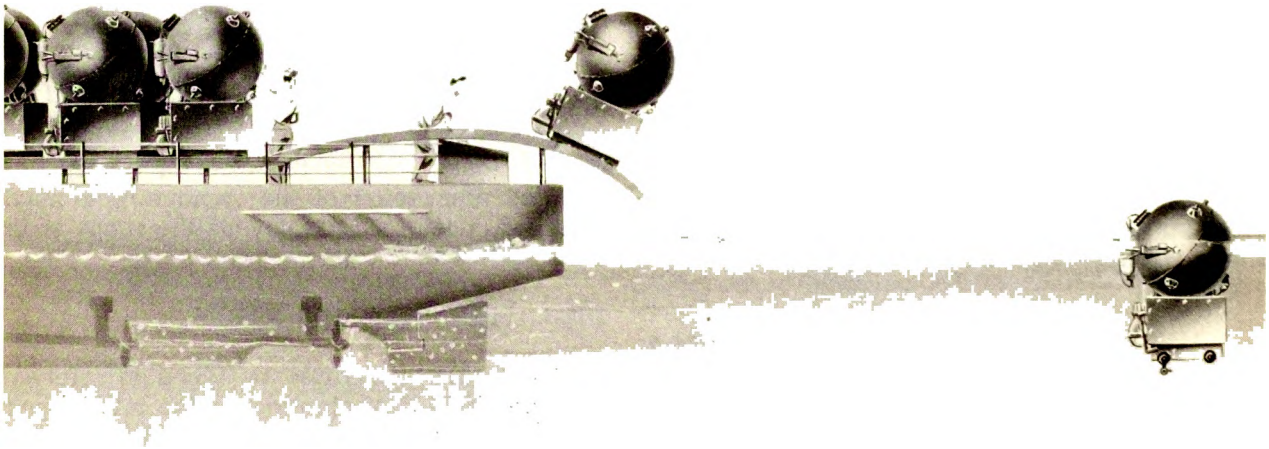

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Figure 10E3.—Surface craft-laid mine.

One of their disadvantages is that once an area has been mined it must be avoided for the armed life of the mines. Therefore submarines cannot repeatedly mine the same area.

Aircraft-Laid Mines

These mines may be carried internally or externally by aircraft, like bombs or torpedoes. Aircraft can carry mines into enemy-held areas, and the field can be replenished over a long period of time without danger from previously laid mines. There can be no secrecy in planting this type of mine, but aircraft can plant mines in enemy-held shallow coastal waters that cannot be mined by other means. Blockading of enemy shipping lanes can be very effectively accomplished by this type of mining.

Although each mine is designed for planting by a particular method, and is so identified, aircraft- and submarine-laid mines may also be laid by surface craft when appropriate adaptations have been made. It is true that at this time no minelayers are in commission but, for limited operations, almost any ship or boat can be adapted to launch mines. This flexibility makes all types of mines available for surface laying.

10E5. POSITION IN THE WATER

There are three classifications of mines according to their position in the water: (1) moored, (2) bottom, and (3) drifting.

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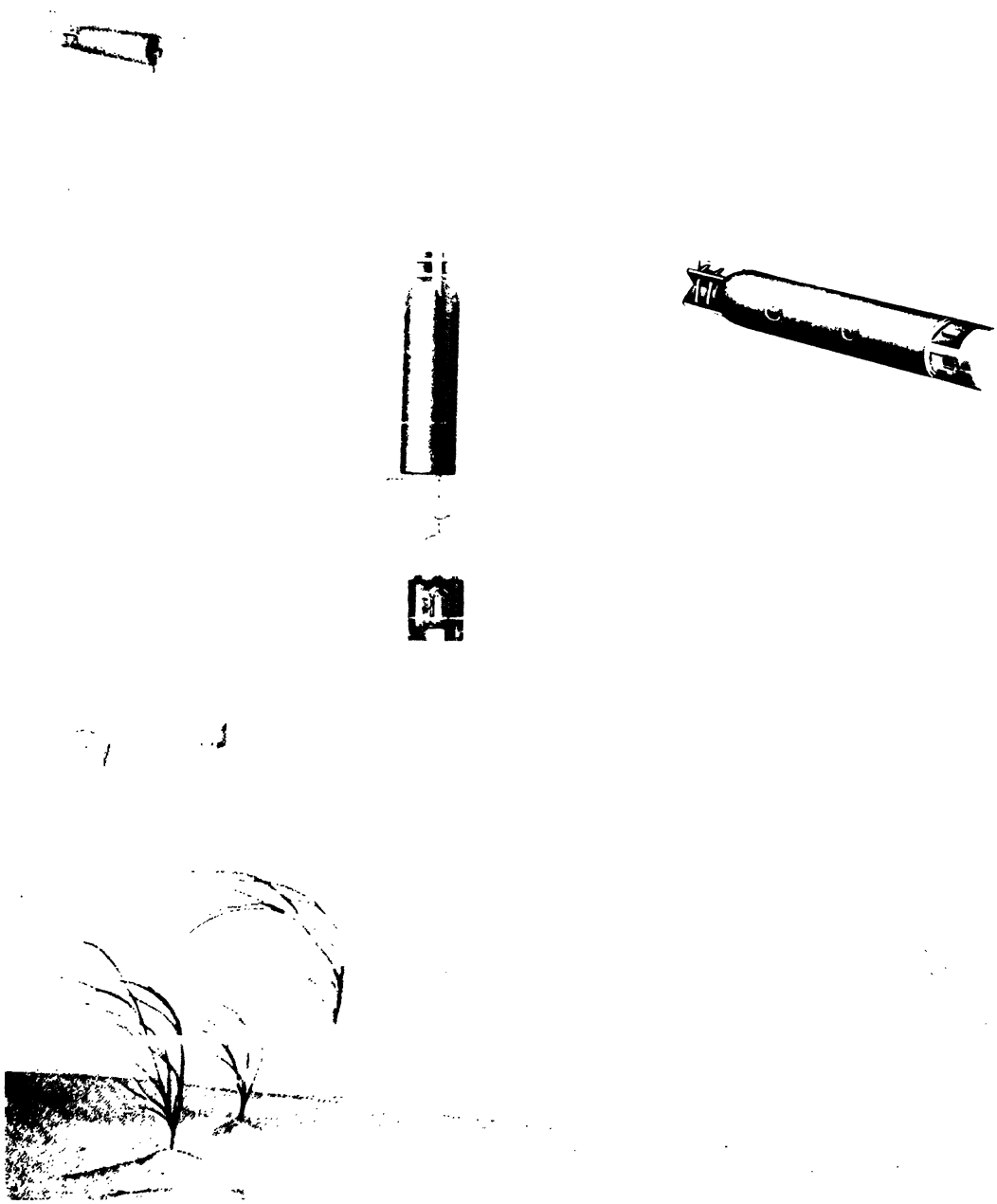

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Figure 10E4.—Submarine - laid mine.

Moored Mine

The moored mine (fig. 10E5) has a buoyant case containing an explosive charge. The case is kept at a predetermined depth by a chain or cable attached to an anchor. This type mine may have either a contact- or influence-firing mechanism. Their main disadvantage is that they may be cleared with comparative ease by mechanical minesweeping gear. (It was for this reason that

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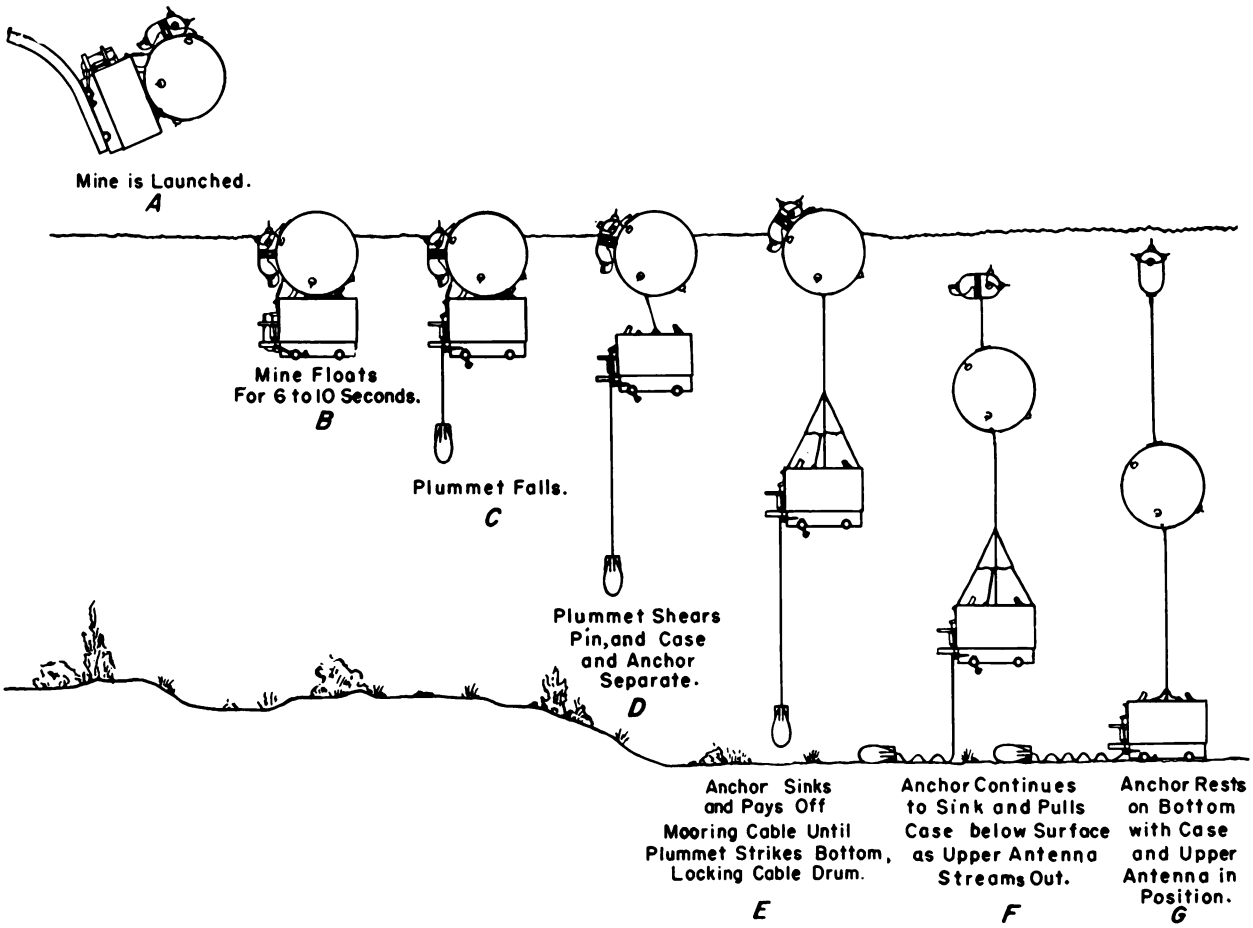

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Figure 10E5.—Sequence of operations in planting a Mk 6 (moored) mine. Schematic.

the bottom mine was developed.) The two most important advantages of the moored mine are: (1) it can be moored so close to the surface that it will be actuated by any ship or boat, no matter how small, that penetrates the minefield, and (2) it may be planted in waters that are too deep for bottom mines, since the case of a moored mine assumes a position some distance from the bottom. The maximum depth of water in which a moored mine can be planted is limited by the downward pull on the case caused by the weight of the cable, and by the drag of tides and currents.

Bottom Mine

This mine (fig. 10E6) was formerly called a ground mine. The naval bottom mine rests on the ocean's bottom, and is held there by its own weight. Mines of this type can be planted by surface craft, submarines, and aircraft; but normally aircraft and submarines are used. This mine generally uses an influence type firing mechanism, (Article 10E6, influence mines) and is not usually effective against surface ships when laid in waters over 30 fathoms deep. However, these mines may be used in deeper water as an anti-submarine weapon. Because this mine lies on the bottom, it requires the enemy to use special and costly minesweeping gear. And the bottom mine is more difficult to detect with locating gear than the moored mine, especially when it lies on soft mud, or on a densely growth-covered bottom.

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56.9.1

Figure 10E6.—A typical bottom mine.

Drifting Mine

(NOTE: The U.S. Navy no longer has a drifting mine in service; however other countries may still use them. The following is for background information only.)

Drifting mines float on or near the surface and move freely with the waves, current, or wind. They may be kept at a set depth by any of several depth-control devices. The fact that these mines do not stay where they are planted can cause a great hazard to our own or friendly ships, as well as to the enemy's ships. Therefore, a drifting mine is designed to have a very short armed life before it sinks itself. A floating mine is not always a drifting mine; the distinction is that a floating mine is a moored mine which has risen to the surface after the cable has parted.

10E6. TYPES BY FIRING MECHANISMS

The third way of classifying mines is by the type of firing mechanism or device used to actuate them. The classification is further divided as follows:

1. Contact mines
   a. Mechanical type
   b. Galvanic action type
   c. Chemical type
   d. Inertia type
2. Influence mines
   a. Magnetic type (influence and induction)
   b. Acoustic type
   c. Pressure type
   d. Combined-usage type
3. Controlled mines

Contact Mines

These mines are fired by actual contact of the mine case or its attachments with the hull of a ship. In the contact class there is one bottom mine which is used as an anti-invasion mine; the rest are moored or drifting mines. Typical contact-firing devices are switch horns, inertia switches, tension-firing mechanisms, and galvanic action or chemical horns.

When the switch horn comes in contact with a ship, it mechanically closes, firing the mine. An inertia switch closes a switch when the mine is bumped by a ship. The tension-firing mechanism is used only in a mine that destroys enemy sweep gear and fires the mine when the sweep cable pulls up against it.

The galvanic action type operates on the principle of the wet cell battery. A steel ship comes in contact with a horn or antenna on the mine, forming a sea cell. The weak current from this sea cell goes to the firing mechanism, initiating the firing of the mine.

The chemical horn also operates on the wet cell battery principle. When a horn is bent, a vial is broken releasing acid to a wet cell battery. The current from this battery fires the mine.

It should be noted that contact-firing devices may be used in moored, bottom, or drifting mines; no other firing principle has been employed operationally in all three of these types.

Influence Mines

These mines are much more complex than contact mines. They are fired by the close approach or passing of a ship. This type of mine is usually of the bottom mine class; it uses

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several different means of actuation. It may be actuated by sensitivity to the target ship's magnetic field, by sensitivity to the ship's underwater sound, or by sensitivity to the reduction of water pressure around the mine caused by the passing of a ship. We have mines which may use only one of the above ways of actuation, but we also have mines which use a combination of all three. The influence mines have a larger target width, and are much harder for the enemy to sweep than the contact mines. In fact, with combinations of firing mechanisms, the influence mine can be made almost impossible to destroy with minesweeping gear.

MAGNETIC MINES.—The magnetic mine is actuated by a change in the earth's magnetic field surrounding it. A steel ship intensifies the earth's normal magnetic field; this change in magnitude or direction of the field, if in the proper sequence, will actuate the firing mechanism. Magnetic firing mechanisms are of two basic types: (1) magnetic dip-needle (influence), and (2) magnetic induction mechanisms.

The MAGNETIC DIP-NEEDLE (or INFLUENCE) mechanism operates on the change in the vertical magnetic field at the mine. The change of this field causes the magnetized needles in the mechanism to dip, closing a pair of electrical contacts and firing the mine. Because the rate of change is unimportant in this mechanism, it is a good mechanism to use in anchorages, or other areas where ships move very slowly. Dip-needle mechanisms can be used in either moored or bottom mines.

The MAGNETIC INDUCTION mechanism, like the dip-needle mechanism, operates on the change of magnetic field of the mine. This mechanism depends primarily on the rate at which the field intensity changes, rather than on the amount of change. A small current is induced in a coil by the changing field. If sufficient potential is developed, a relay is actuated, closing the firing circuit. This type of mechanism is used in bottom mines, in areas where ships are under way at normal speeds.

ACOUSTIC MINES.—The acoustic mine operates on the noise produced by a ship's propeller(s), engines, and hull. A microphone converts these sound vibrations into electrical impulses, which are fed into an amplifier. The mechanism will actuate only when it receives sound impulses of proper intensity, rate of change of intensity, frequency, and duration. If the noise does not meet the above specifications the mechanism will not actuate, thus protecting the mine from random underwater noises. This mechanism, like the magnetic induction mechanism, is used in bottom mines.

PRESSURE MINES.—This mine's firing mechanism is actuated by the change in water pressure caused by a moving ship. A passing ship momentarily increases the pressure as the ship's bow wave passes. This increase is followed by a reduction in pressure for a sustained period (fig. 10E7). Contrary to popular belief, it is this reduced pressure, rather than increased pressure, that operates the mechanism. This mechanism is used only in bottom mines, and only in areas where ships are under way at normal speeds. The pressure mechanism is probably the most difficult to sweep of any single mechanism.

COMBINATION MINES.—A combination of mechanisms improves the usefulness of a mine in that it is less likely to be actuated by false targets. Also it makes the mines harder to

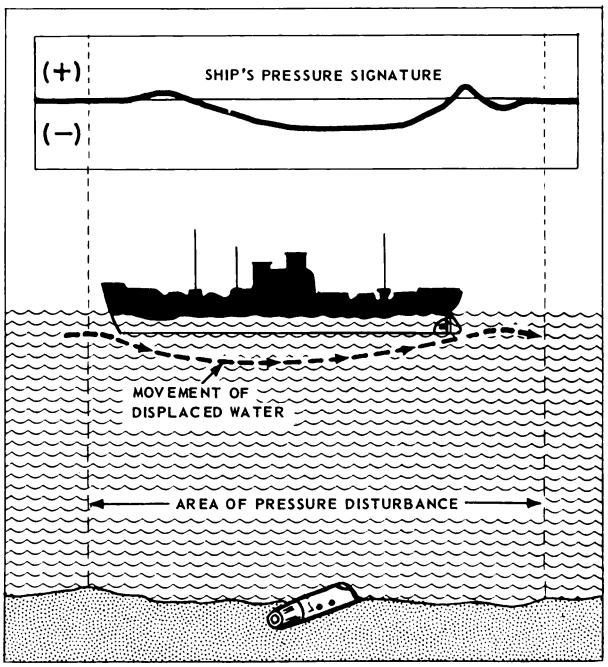

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Figure 10E7.—Pressure signature.

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sweep. For the mine to fire, all the incorporated firing mechanisms have to be actuated within a specified time limit. The first mine of this type was pressure-magnetic, and was used in the aircraft-planted bottom mine and later in the submarine-laid bottom mine. We now have mines that use a combination of all three types of firing mechanisms at one time. Once again, this improvement makes mines of this type almost impossible for the enemy to sweep.

Controlled Mines

Controlled mines are electrically connected to a shore station by a cable. These mines are designed to be rendered safe or fired manually. They are the largest of all our bottom mines, and have to be laid by surface ships. The biggest advantage of the controlled mine over all others is that it permits positive target selection. Friendly shipping can pass safely through this field, while an enemy ship is destroyed by personnel in the control station. These mines are used to protect our own harbors where the area can be under visual surveillance most of the time. The greatest disadvantage of the controlled mine is its dependence on accessories. Loss of the control station, or damage to control cables, may nullify the field's effect. For this reason a controlled field has to be constantly maintained, and the control station requires a constant watch by trained personnel.

10E7. LIFE CYCLE OF MINES

The life cycle of a mine follows the same pattern as that of a living thing. It can be said that a mine is born when it is planted, and lives for the armed life set for it. It dies when it is exploded, or when it is rendered safe by the sterilizer device. Because much of the life cycle is the same for all mines, only one contact type and one influence type mine will be discussed.

CONTACT MINE

The Mk 6 surface-craft-laid moored mine which is typical of most contact mines, will be discussed. The mine is carried on the launching rails of the planting ship, on wheels attached to the mine anchor. When the area to be mined is reached, shipping safety features are removed from the mine. When the order is received to plant a mine, the launching crew rolls a mine off the stern of the ship. After the mine is in the water, its case and anchor separate. The anchor sinks to the bottom, and the case finds its mooring depth. At this time the mine cannot be detonated, because of safety features designed to protect the planting vessel. After a predetermined time the mine is armed, and will blow up when any ship (friend or foe) comes in contact with it. Mines are designed to render themselves safe after the usefulness of the minefield has lapsed. This feature is necessary because it is unlikely that all of the mines in a field will be actuated by enemy ships, and we may later want to use the area for our own ships.

INFLUENCE MINE

An influence mine is mounted on or in an airplane at its home base. At the proper time the plane will carry the mine to the area to be mined, and drop it as it would a bomb. The mine has a parachute attached which slows it as it drops. When the mine hits the water, the parachute separates from the case, and both case and parachute sink to the bottom. The delay arming safety features start operating to arm the mine. Like the contact mine, this mine can be actuated by any ship, but in the case of influence mines the ship has to meet certain specifications to actuate the firing mechanism.

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F. Mine Components and Accessories

10F1. MAJOR COMPONENTS

The major components of a mine are the case, the explosive filler, the anchor (if one is used), and the firing mechanism with its accessories.

The mine case provides a watertight compartment for the main charge and the firing system. The bursting charge occupies the main compartment, and in bottom mines will fill most of it. In moored mines, the case must be large enough to provide air space for buoyancy. Smaller compartments in the case house and secure the batteries, firing mechanism, and accessories.

Mine cases are usually made of steel, but a nonferrous metal is required when certain influence firing mechanisms are to be used.

Anchors for various moored mines naturally differ in size, shape, and method of operation. All must be capable of mooring the mine at a preset depth below the surface. For ease in handling, the anchor is assembled integrally with the case.

The operation of the anchor assemblies during planting of a typical moored mine is illustrated in figure 10E5. Note that this surface-laid assembly has a net positive buoyancy until the case and anchor are separated, flooding the anchor. Conversely, aircraft-laid or submarine-laid assemblies, which are employed in offensive mining operations in enemy waters, have a net negative buoyancy and never reach the surface after planting. Magnetic, needle-type bottom mines designed to be planted from 21-inch submarine torpedo tubes may be used in depths of 16 to 125 feet against surface craft, and in depths to 500 feet against submarines.

Most of the standard naval mine cases will accommodate a choice of explosive fillers and a choice of the various firing systems and accessories. Because of this, the mark designation of the mine usually applies only to the assembled case and anchor. On the other hand, a specific modification of a production mine usually designates its explosive filler, firing systems, accessories, and the special features which adapt this mine to surface, submarine, or aircraft planting.

10F2. MAJOR ACCESSORIES

As mentioned earlier in the chapter, mines are complex weapons that use many separate units to increase their effectiveness. Some of these accessories are safety devices, other increase the efficiency of the planted mine. A few of the more important mine accessories are defined briefly in the following paragraphs.

1. The EXTENDER mechanism is a hydrostatically operated device used to hold the mine detonator a safe distance from the booster charge until the mine sinks to a certain depth.

2. HYDROSTATIC SWITCHES are used to close electric contacts by means of hydrostatic pressure working against spring pressure.

3. The ARMING DEVICE is an extender and hydrostatic switch assembly which aligns an explosive train and operates electrical contacts when subjected to hydrostatic pressure.

4. The CLOCK STARTER mechanism is a hydrostatically operated device used to start the clock delay mechanisms when the mine sinks to a certain depth.

5. CLOCK DELAY mechanisms delay the arming of the mine for a preset time after planting. This allows the planting craft time to plant a large minefield before the mines become dangerous. Clock delays are also used to stagger the arming of mines in a field to improve its effectiveness. Clock delay mechanisms are of two basic types: hand wound and motor wound. Hand-wound clocks may be set to provide a delay in arming of 1/2 to 10 days, while motor-wound clocks provide a delay of 3 to 100 days.

6. The STERILIZER mechanism is used to limit the armed life of a mine to a predetermined time. It renders the mine inoperative by shorting out the battery, or in some cases by opening the detonator circuit.

7. BATTERIES, used in mines are all of the dry cell type. Each is composed of several cells arranged in a waterproof container. The batteries provide the required voltages and current to operate the mine accessories and the firing system to fire the detonator at the proper time.

8. The ACTUATION COUNTER (sometimes called a ship's eliminator or ship's counter) is designed to delay firing the detonator until the firing mechanism has completed its operation a predetermined number of times.

9. SEARCH COILS are used in magnetic induction mines to detect changes in the earth's magnetic field around the mine.

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10. The MICROPHONE or HYDROPHONE contains a crystal which changes sound energy into electrical energy to actuate the acoustic firing mechanism.

11. CONTROL BOX is a device which performs switching and timing functions. It ensures that certain requirements are met before the mine will fire.

12. SENSITIVITY SWITCHES are provided to adjust the sensitivity of the firing mechanism of a mine for best use against an intended target.

13. HYDROSTATIC RELEASES are mechanisms used to release a device from a mine, or to separate two cables at a predetermined depth.

14. PARACHUTE PACKS are metal or plastic-and-canvas containers holding a parachute, which is used to reduce the impact velocity of an aircraft-laid mine when it enters the water. This protects other mine accessories from damage that would result if the mine were allowed to fall freely and strike the water at high speed.

G. Types of Minefields

10G1. INTRODUCTION

The subject of minefields is a very large one, and space is not available in this text to cover it fully. More detailed information can be found in NWP-26(A) (MINING OPERATIONS).

A mine is a complex weapon designed to do the same job as a gun or torpedo. The big difference of course is that mines are rarely used one at a time; a group of mines are used together to make up a minefield. The two main purposes of these fields are first, to destroy or disrupt enemy shipping—both combatant and noncombatant; and secondly, to protect United States and Allied shipping and Allied controlled activities.

The types of field in which mines are planted is dictated by the specific situation. The choice of field type is an application of the potentialities of mines and layers to the problems which the situation presents.

Minefields may thus be divided according to purpose into two broad groups: Defensive and Offensive, with variations to make them more effective.

10G2. DEFENSIVE FIELD

A defensive minefield is similar to a defensive football team in that they both try to hold back the opposition. Defensive mining attempts to keep the enemy guessing at all times. In some cases however, the field is well advertised to the enemy. This adds to the effectiveness of the field, since the enemy may decide against entering these waters due to the potential danger. The area may still be utilized by our forces and allies provided with charts showing the mine-free navigable channels. Some of the specific ways in which mines may be used defensively are as follows:

1. In large harbors and anchorages for permanent harbor defense.
2. To protect advance base anchorages.
3. To protect assembly points for convoys.
4. To protect coastal shipping lanes from seaward attack.
5. As a submarine trap.
6. As anti-invasion fields.

10G3. OFFENSIVE FIELD

The offensive minefield can be compared with a football team on the offense, in that they both take the action to the opponent. These fields are laid in enemy-held or disputed waters to disrupt enemy shipping. Offensive minefields do this by destroying or damaging the enemy's ships, or by making areas unusable because the threat of losses is so great. Offensive mines were used very effectively in Operation Starvation (fig. 10G1) during World War II as mentioned earlier in this chapter.

Offensive minefields are divided into two types: TRANSITORY ATTRITION and SUSTAINED ATTRITION. In this case attrition means wearing down the enemy by disrupting his means of supply by ships.

Transitory Attrition Fields

These are fields where a few mines are laid in an area in which traffic is sufficient to give a reasonable probability of a casualty. From the meaning of transitory, obviously this field is designed to last only a short time. The field

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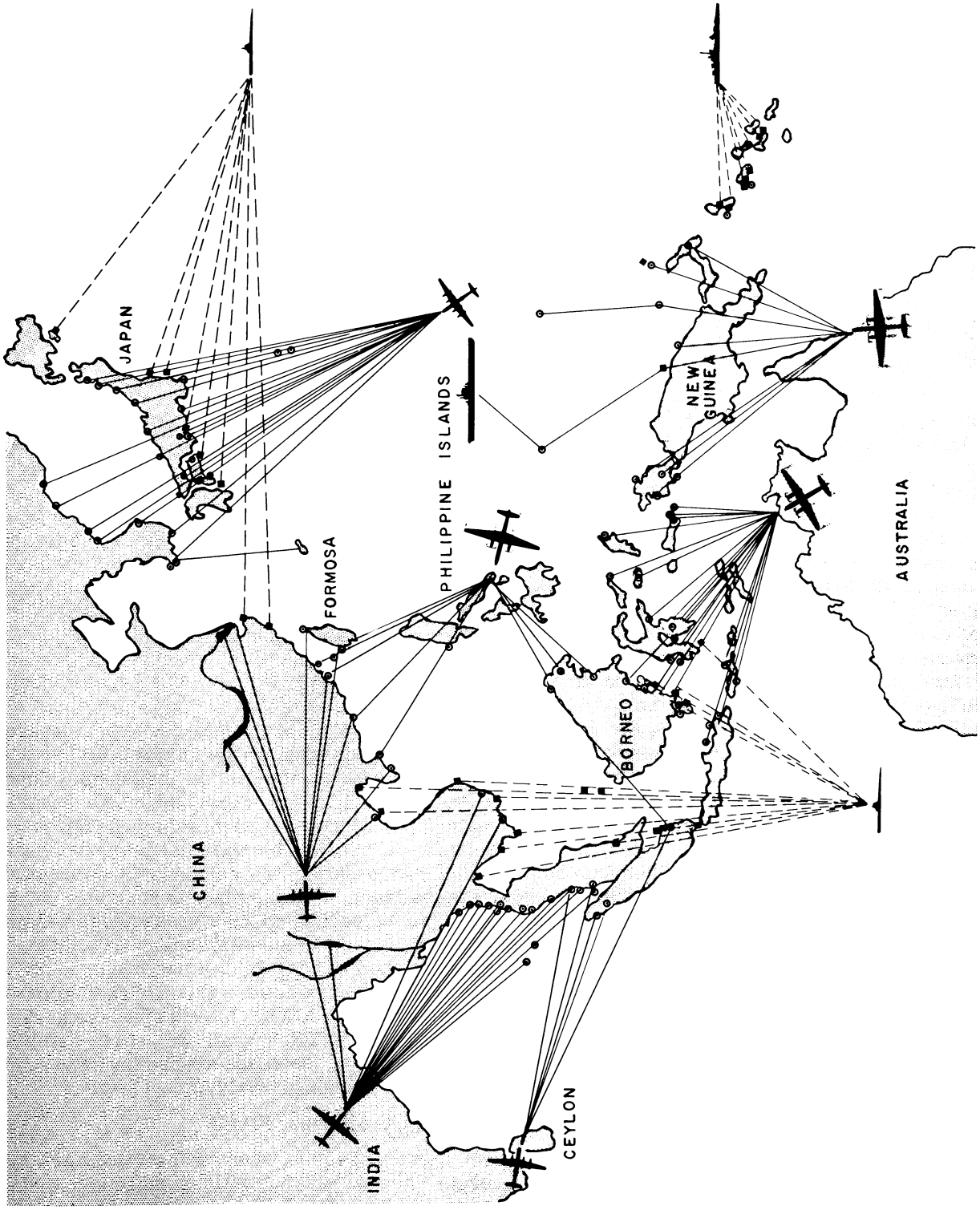

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Figure 10G1.—Offensive minelaying campaign against Japan. (Operation Starvation).

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can be swept easily or avoided by the enemy, and mines that are destroyed are usually not replaced.

Sustained Attrition Fields

These fields are laid where they cannot be easily avoided by enemy traffic. They are maintained for a prolonged period of time by replacing mines which have been blown up by a target or by enemy minesweeping. If the casualty rate is so high that the enemy cannot afford the losses, the minefield can deny them the use of the channel or area.

Mines are an excellent STRATEGIC weapon in that mining operations can be carried out over a prolonged period without regard to other military activities. Mines destroy the enemy's war-making potential behind their own lines. On the other hand, a mine is a poor TACTICAL weapon because of the lengthy and detailed preparation necessary for planting a minefield. A tactical weapon is one designed for supporting or protecting a single engagement, and time usually does not permit the use of mines for this purpose.

The design of a minefield depends on the purpose of the field and on the countermeasures expected. They are divided into six types:

1. Countered fields are those which the enemy is expected to counter by minesweeping or hunting.
2. Uncountered fields are those which the enemy is not expected to counter by minesweeping or hunting.
3. Protective fields primarily protect what lies behind the field by hindering or preventing the enemy's approach.
4. Attrition fields are thos intended primarily to cause damage to enemy ships.
5. Nuisance fields are those where a few mines are laid to harass the enemy.
6. Dual Purpose fields are those having more than one purpose.

10G4. MINELAYING

A sudden massive attack by minelaying aircraft is considered to be one of the greatest threats to any maritime power that exists today. So great, in fact, that the possibility of such an attack requires major expenditures of manpower and equipment in conducting countermeasure operations, whether a single mine has been laid or not.

Offensive minelaying by surface craft has comparatively limited application in enemy-held waters. The utmost secrecy can, of course, be obtained by laying mines from submarines. However, a submarine cannot replenish the interior of an existing minefield without itself being exposed to an unacceptable amount of danger. That brings us to the use of aircraft. The aircraft naturally leads in its ability to lay mines suddenly and in great quantity. It is, further, as mentioned earlier, the only craft capable of replenishing a large existing field without danger from the field itself. Offshore shipping lanes can be mined by bombers and patrol planes whenever the depth of water is not too great. Mining of enemy-held rivers and harbors would generally be effected by tactical aircraft under conditions of low visibility or under cover of diversionary raids.

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H. Mine Countermeasures

10H1. GENERAL

Mine countermeasures include all actions taken primarily to protect own or friendly shipping against mines, including (1) reducing the effectiveness of enemy mines, and (2) clearing areas mined by friendly forces, after these areas have served their purpose. The three major types of mine countermeasures are ship treatment (against magnetic and acoustic mines), mine hunting, and minesweeping.

10H2. SHIP TREATMENT AGAINST MAGNETIC MINES

There are two principal methods (deperming and degaussing) of treating a steel ship hull to decrease the magnetic effects that actuate magnetic mines. Before taking these up, let us consider in more detail the characteristics of a ship's magnetic field.

Any ship's magnetic field can be analyzed into two main components—its permanent field and its induced field.

Permanent magnetic field. When a ship's hull is being fabricated in a shipyard it is subjected to heat (welding) and to impact (riveting). Ferrous metal contains groups of iron molecules called "domains." Each domain is a tiny magnet, and has its own magnetic field with a north pole and a south pole. When the domains are not aligned along any axis, but point in different directions at random, there is a negligible magnetic pattern. However, if the metal is put into a constant magnetic field and its particles are agitated (as they would be by hammering or by heating), the domains tend to orient themselves so that their north poles point toward the south pole of the field, and their south poles point toward the north pole of the field. All the fields of the domains then have an additive effect, and a piece of ferrous metal so treated then has a magnetic field of its own. You can demonstrate this by hammering on an unmagnetized piece of steel such as a knife blade in a strong magnetic field; the steel will develop a permanent field. The effect occurs (though to a lesser extent) even if the magnetic field is not strong. Although the earth's magnetic field is not strong, a ship's hull contains so much steel that is acquires a signigicant magnetic field during construction.

Induced magnetic field. Imagine a magnetic field as consisting of many tiny "lines of force"[1] —running from the magnetic north pole to the magnetic south pole of the field in a closed loop. The earth has such a field, as if it contained a huge bar magnet (fig. 10H1). The magnetic poles do not coincide with the geographic poles, however.) Visualize an area of the earth's surface, with the invisible magnetic lines of force more or less evenly distributed over it. Air and water have low magnetic permeability—that is, they do not conduct magnetic lines of force (or magnetic flux) especially well. Now put a ship's hull into the sea at the point being considered. Ferrous metal has relatively high permeability. The high-permeability hull distorts the field because the magnetic lines of force tend to concentrate in it. If the ship is pointed toward magnetic north, the effect is as shown in figure 10H2, part A: if the hull is pointed eastward, the effect is as shown in part B of the figure.

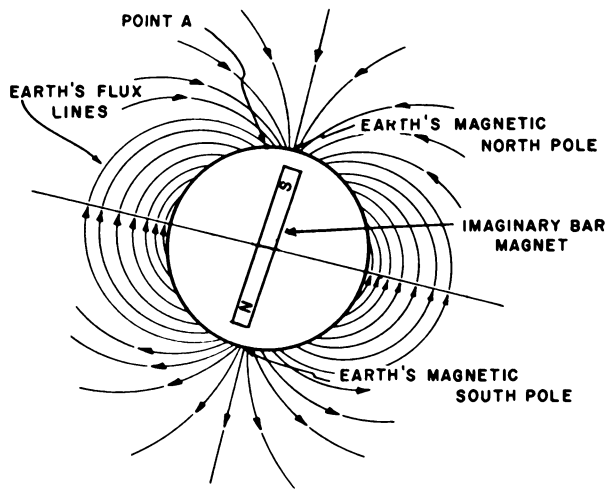

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Figure 10H1.—The magnetic field about the earth.

[1] The idea of "lines of force" is intended only as an aid in thinking of the effects of magnetic fields. Their existence has not been physically demonstrated, and the idea should be considered only as a conceptual convenience, not as a physical fact.

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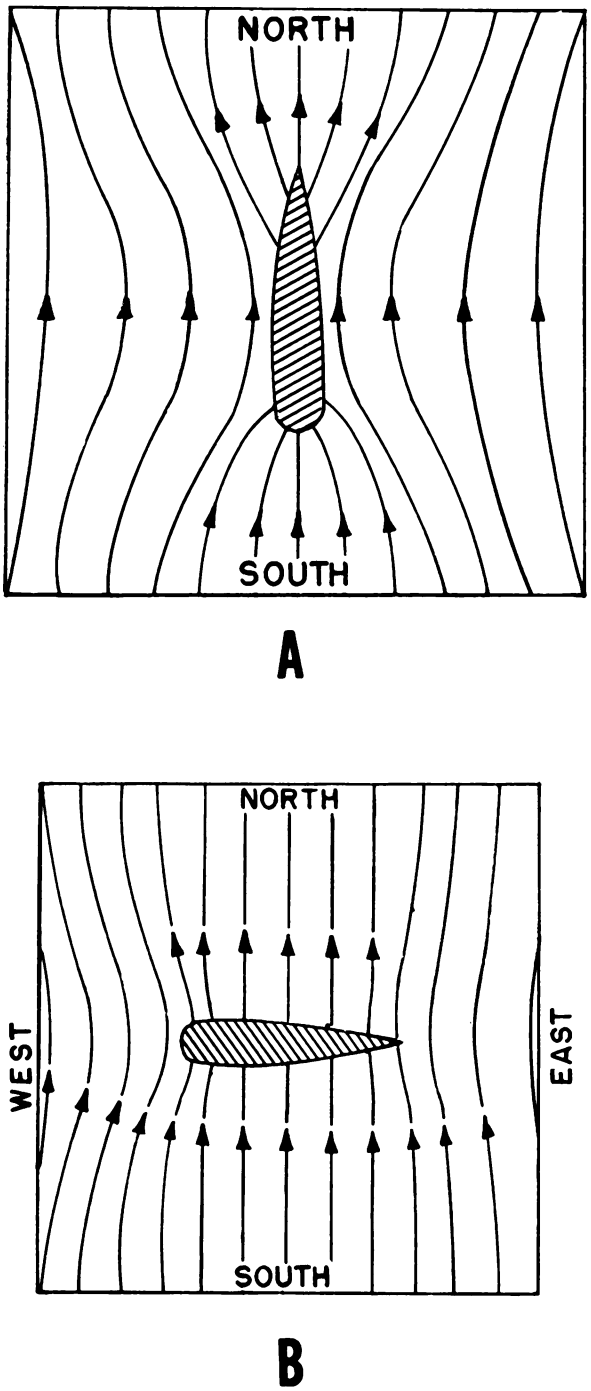

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Figure 10H2.—How a ship's hull distorts the earth's magnetic field.

This distortion of the earth's field (by concentrating part of it in the magnetically permeable hull) is the induced field. Figure 10H2 shows only the plan projection of the field. As figure 10H1 shows, however, the magnetic lines of force of the earth's field are not parallel to the earth's surface except in the vicinity of the equator. Elsewhere they are tilted with respect to the surface; at the magnetic poles they are perpendicular. The induced field therefore has a vertical component as well as a horizontal. The strength of the vertical component is affected chiefly by the ship's location on the earth with respect to the magnetic poles. The horizontal component is affected chiefly by the direction in which the hull is pointing with respect to a line connecting the magnetic poles. Figure 10H2 illustrates the latter effect.

Deperming. The purpose of deperming is not to eliminate a steel hull's permanent magnetic field altogether (this is not practical on a large scale), but to (a) reduce it to a minimum, and (b) make it more or less similar to others of the same hull type. At a number of locations called magnetic or degaussing ranges, magnetic sensing devices located on the bottom of a channel can detect a ship's magnetic field pattern as it steams past. The recording made of the ship's magnetic pattern is called its magnetic signature. After deperming, a ship's permanent magnetic field has not only been reduced to a practicable minimum, but its signature is similar to that of other depermed ships of the same class. The degaussing installation (described below) can then be set up on a "mass production" basis. The deperming process cannot be described here in detail; suffice it to say it is essentially a large-scale version of the process for demagnetizing a watch.

Degaussing. The purpose of degaussing is to counteract the ship's magnetic field so that (ideally) the magnetic field near the ship is the same as it would be if the ship weren't there. To some extent this can be done by magnetic treatment of the ship using coils temporarily installed. This is not as effective as the more frequent method—using permanently installed equipment, as follows:

1. Degaussing coils.
2. A d-c power source to energize the coils.
3. Means to control the currents in the coils.
4. Magnetic compass compensating equipment to cancel out the disturbing influence of the degaussing equipment on the magnetic compass.

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Degaussing cannot be exhaustively described in this text. The interested student is referred to chapter 81 of the Bureau of Ships Technical Manual. The term "degaussing" is derived from "gauss," the unit of magnetic field strength (in turn, the name of this unit commemorates the German 19th-century mathematician Karl Friedrich Gauss). We can cover here only some high points.

The ship's magnetic field (permanent plus induced) can be analyzed into 6 components. The degaussing installation is designed to produce as accurately as possible an exactly opposing field. This is done by encircling the hull or other parts of the ship's structure by coils of heavy electric cable. The coils are designated as M (main coil), F (forecastle), Q (quarterdeck), L (longitudinal), and A (athwartship). See fig. 10H3). Various combinations of these are energized as required to create the desired fields. The coils are excited either by the ship's d-c supply or by a motor-generator which produces the d-c required. The polarity and current in each coil may be manually controlled, but the present trend is to make the functioning of the system completely automatic, except for manual setting of magnetic latitude and magnetic variation (i.e., difference between the direction to the geographic pole and to the magnetic pole). Such a system may compensate for ship's heading only, or for heading, roll, and pitch, by using servos to vary the d-c inputs to the coils.

Nonmagnetic construction. Effective though deperming and degaussing are, residual magnetic fields accompany all steel-hull ships, especially larger ones. For such critical work as minesweeping, more drastic antimagnetic measures are necessary. Minesweepers therefore may be built with nonmagnetic hulls to reduce magnetic effects to the vanishing point.

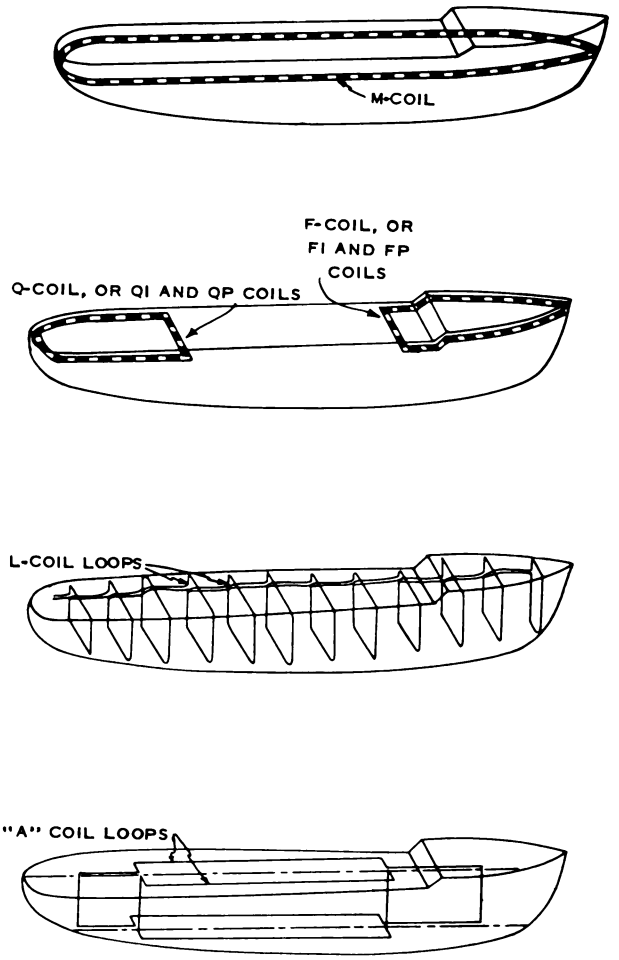

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Figure 10H3.—Degaussing coils.

10H3. SHIP TREATMENT AGAINST ACOUSTIC MINES

Acoustic mines function in response to the underwater sound output of ships. Most underwater noise of ships is caused by movement of the screw blades with respect to the water. At high screw speeds parts of the screw move so fast the water cannot flow around the screw edges fast enough, causing low pressure areas to form, then collapse. These actually are cavities or bubbles of water vapor, and their rapidly repeated formation and collapse produces water vibration at sonic or subsonic frequencies. Other causes of ship noise are vibration of external parts in the water as the ship passes through, water flow over sharp surfaces or obstruction of the hull, and transmission through the hull, screws, and screw shafting of machinery noises to the water.

The only important design change that could materially change acoustic disturbances caused by ships would be the development of a screw shape that would reduce cavitation or cavitation noise at high speed. Research is now under way on this. For the rest, once the ship's hull has been adequately faired, little can be done so far as design is concerned to reduce acoustic noise output. Noise can be reduced only by reducing screw speed, shutting down noise-producing machinery such as reciprocating pumps, etc.

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10H4. MINE HUNTING

The methodical detection, location, and neutralization of mines is appropriately called mine hunting. Some craft and their highly trained personnel specialize in this work.

The shipboard devices used in mine detection are called ordnance locators. The sensing component of an ordnance locator is called an ordnance detector. The term ordnance detector can also refer, however, to a small, man-carried ordnance locator in its entirety.

11H5. MINESWEEPING

The process of clearing a given region of mines is called minesweeping. Mechanical devices, explosive charges, and apparatus for producing influence fields may all be needed in the sweeping of a single field.

To sweep moored contact mines, it is necessary to cut the mooring cable. The mine's buoyancy carries it to the surface, where it is destroyed by gunfire. The mooring cable can be cut by mechanical or explosive cutters "streamed out" from the ship on a sweeping cable. One end of the cable is secured to the vessel that is sweeping the mines; the other is attached to a sort of underwater kite with curved fins that force it to keep the cable streamed out as it is hauled through the water. Floats and depressors are used to help keep the cable at the proper depth. The kite is called an otter. Gear of this type (called Oropesa gear) is used by minesweepers. Individual ships have somewhat simplified minesweeping equipment that works on the same principle. Figure 10H4 shows the business end of this equipment—a paravane (a kitelike device whose function is similar to the otter's) and a cutter in the act of cutting a mine cable.

Some magnetic mines are capable of being swept by towing a buoyed electric cable over them. The strong magnetic field set up by this cable causes the mine to detonate. Since these mines are designed to function as the peak of the magnetic field passes, they are not set off by the relatively weak field of the minesweeper. Through use of advanced degaussing systems, and nonmagnetic construction materials, new designs of minesweepers reduce their magnetic fields to a minimum.

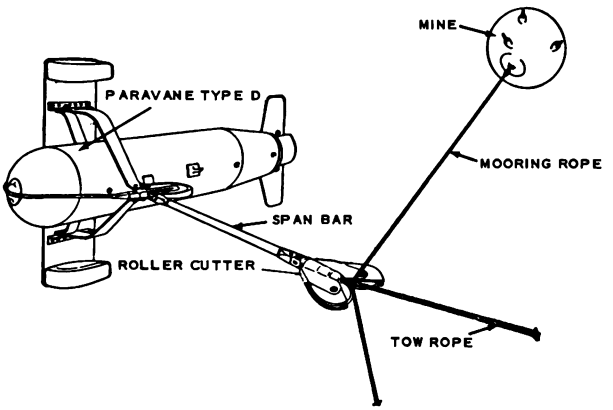

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Figure 10H4.—How a paravane cuts a moored mine's cable.

Some acoustic mines are swept by creating underwater sounds of proper intensity and quality to actuate the mine-firing mechanism. Noise makers are of various types, some being towed astern by a sweep wire and others being located in the bow of the minesweeper to direct the noises ahead of the vessel. New types of engine mountings and other noise-reducing devices are at present being applied to minesweepers to reduce acoustic disturbances by their own propulsion equipment, and thus improve their ability to sweep acoustic mines with safety.

10H6. OTHER COUNTERMEASURES

In addition to the three major types of countermeasures, various other protective measures may be taken. These include mine watching, prevention of enemy minelaying action, and the use of long-range detecting and actuating devices.

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CHAPTER 11

ANTISUBMARINE WARFARE

A. The Submarine Problem

11A1. BACKGROUND

The classical concept of the Navy's wartime mission, as expressed early in this course, is to maintain command of the seas so that we can use it and at the same time deny its use to the enemy. A recent corollary to this concept adds a new method of attack to the Navy's arsenal—the guided missile launched against major enemy land targets by naval vessels hundreds or thousands of miles distant—and simultaneously lays on the Navy the chief burden of defending U.S. territories against just such attack by the enemy.

The submarine has roles to play both in the classical concept of the Navy's mission and in these newer corollaries. We know that the enemy is capable of pitting against us submarines as advanced as our own, and as well (or even better) adapted to launching guided missiles with nuclear war heads against our own cities. Such activities as the prodigious and continuing production of Soviet submarines show that the military planners of foreign countries are by no means incapable of making similar strategic estimates—and acting upon them.

Against this threat, unprecedented in the history of warfare, it is the Navy's primary responsibility to maintain constant vigilance, and to be continuously prepared to prevent and counter every attack. It is no longer enough to prevent submarine attacks on our own or allied shipping and naval vessels, important though this is. It has become necessary to protect against missile-carrying submarines wherever they may be. This new dimension added to the concepts of ASW[1] sets up a new requirement. The need is to find and keep under surveillance all enemy submarines before they can reach a spot within missile launching range of our coasts.

Most of what has even now been developed by way of doctrine techniques, and equipment cannot be completely revealed in this textbook for security reasons. But the student should realize that a massive effort by the Navy and other agencies, both in and out of the armed forces, is under way to solve the problems implied by this threat, and he should realize too that when he is on active duty the chances are very good that he will be called upon to participate in this effort.

Let us now go on to consider briefly the submarine threat as it has been in the past and as it may be in the future. In this article and in the remainder of this chapter we are primarily concerned with how the submarine can be detected, located, and attacked by surface forces with the aid of friendly air and subsurface forces. The strategic role of the submarine as a guided-missile platform is beyond the scope of this chapter.

11A2. HISTORICAL INTRODUCTION AND DEVELOPMENT

The first successful submarine was built in 1620 by Cornelius Van Drebel, a Dutch physician. During repeated trials in the Thames River, he maneuvered his craft successfully at depths of 12 to 15 feet beneath the surface.

Various other European designers of that time constructed submersible craft also. But they failed to arouse the interest of any navy in an age when all concepts of the potentialities of submarine warfare still were far in the future. Most of the early craft were of wooden frames, covered with greased leather or similar material, and propelled by oars. Different methods of submerging were thought of and some were

[1] The phrase "antisubmarine warfare" is generally abbreviated "ASW." The abbreviation "A/S," meaning "antisubmarine," is an adjectival form.

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even tried. One inventor's design consisted of a number of goatskin bags built into the hull, each connected to an aperture in the bottom. He planned to submerge the craft by filling the skins with water, and to surface it by forcing the water out of the skins with a "twisting rod." Although his vessel was never built, it seems that this was the first approach to the modern ballast tank. Another inventor actually submerged his craft by reducing its volume as a result of contracting the sides through the use of hand vises.

Ideas were plentiful, some of them fanciful and grotesque, but some contained elements capable of practical application. Lack of full understanding of the physical and mechanical principles involved, coupled with the almost universal conviction that underwater navigation was impossible and of no practical value, kept postponing the attempt to utilize a submarine in naval warefare during the early period.

A submarine was first used during the American Revolutionary War as an offensive weapon in naval warfare. The Turtle (fig. 11A1), a one-man submersible designed by an American inventor named David Bushnell and hand-operated by a screw propeller, attempted to sink a British man-of-war in the New York Harbor. The plan was to attach a charge of gunpowder to the ship's bottom with screws and explode it with a time fuze. After repeated failures to force the screws through the copper sheathing of the hull of HMS Eagle, the submarine gave up, released the charge, and withdrew. The powder exploded without result, except that the Eagle at once decided to shift to a berth farther out to sea. Although the attack was unsuccessful, the "idea" for a submarine was there, and it grew until the submarine eventually became a potent weapon for attacking ships.

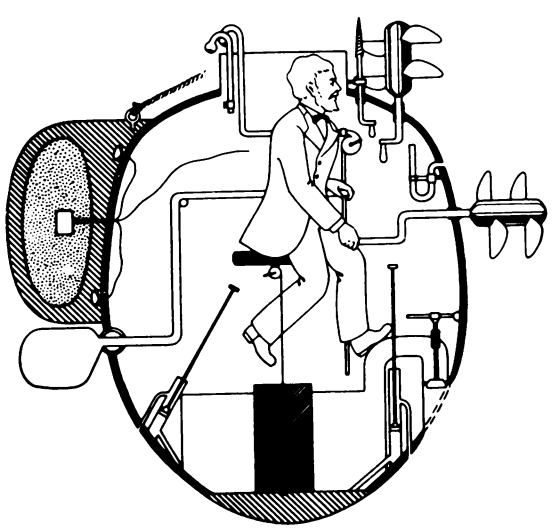

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Figure 11A1.—The Turtle of David Bushnell, from a drawing by Lt. F.M. Barber, USN, 1875.

On 17 February 1864, a Confederate craft, a hand-propelled submersible, carrying a crew of eight men, sank a Federal corvette that was blockading Charleston Harbor. This is the first recorded instance of a submarine sinking a warship. The hit was accomplished by a torpedo suspended ahead of the Confederate Huntley as she rammed the Union Frigate Housatonic.

The submarine first became a major component in naval warfare during World War I, when Germany demonstrated its full potentialities. Wholesale sinking of allied shipping by the German U-boats almost swung the war in favor of the Central Powers. Then, as now, the submarine's greatest advantage was that it could operate beneath the ocean surface where detection was difficult. Sinking a submarine was comparatively easy, once it was found—but finding it before it could attack was another matter.

During the closing months of World War I, the Allied Submarine Devices Investigation Committee, termed ASDIC, was formed to obtain, from science and technology, more effective underwater detection equipment. The committee developed a reasonably accurate device for locating a submerged submarine. This device, a trainable hydrophone, which is attached to the bottom of the ASW ship, and is used to detect screw noises and other sounds that might come from a submarine. Although the committee disbanded after World War I, the British made improvements on the locating device, during the interval between then and World War II, and named it ASDIC after the committee.

American scientists further improved on the device, calling it sonar, a name derived from the initials of the words sound navigation, and ranging.

In World War II, submarines sent millions of tons of shipping to the bottom. In what since has come to be known as the Battle of the Atlantic, the U.S. Navy and her Allies teamed together to hunt down undersea raiders, thus gaining one of the important victories of the war.

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At the end of World War II, the United States improved the snorkel (a device for bringing air to the crew and engines when operating submerged on diesels) and developed the Guppy submarine. The Guppy (short for greater underwater propulsion power) is a conversion of the fleet-type submarine of World War II fame. Figure 11A2 illustrates a fleet-type submarine before conversion to Guppy. A Guppy submarine is shown in figure 11A3. The only change in outward appearance is the superstructure. It was changed by reducing the surface area, streamlining every protruding object, and enclosing the periscope shears in a streamlined metal fairing. Performance increased greatly with improved electronic equipment, additional battery capacity, and the addition of the snorkel.

11A3. NEW DEVELOPMENTS

The world's pioneer nuclear-powered submarine is the USS Nautilus (SS(N) 571). (fig. 11A4). The Nautilus, commissioned in September 1954, is 320 feet in length. Its standard surface displacement (ssd) is 3180 tons. She is designed for traveling faster under the water than on the surface. The Nautilus introduced the bulbous bow for better underwater performance. She refueled for the first time in 1957.

An intensive building program for nuclear submarines is now in effect and many new ships presently are operational with the fleet. Among these is the USS George Washington (SSB(N) 598), (fig. 11A5) which was the first of the Polaris missile submarines.

One of our fastest submarines is the USS Skipjack (SS(N) 585) (fig. 11A6). This is the first nuclear submarine whose hull is a radical departure from the conventional idea of submarine hulls. She also has diving planes on the sail, which results in increased maneuverability.

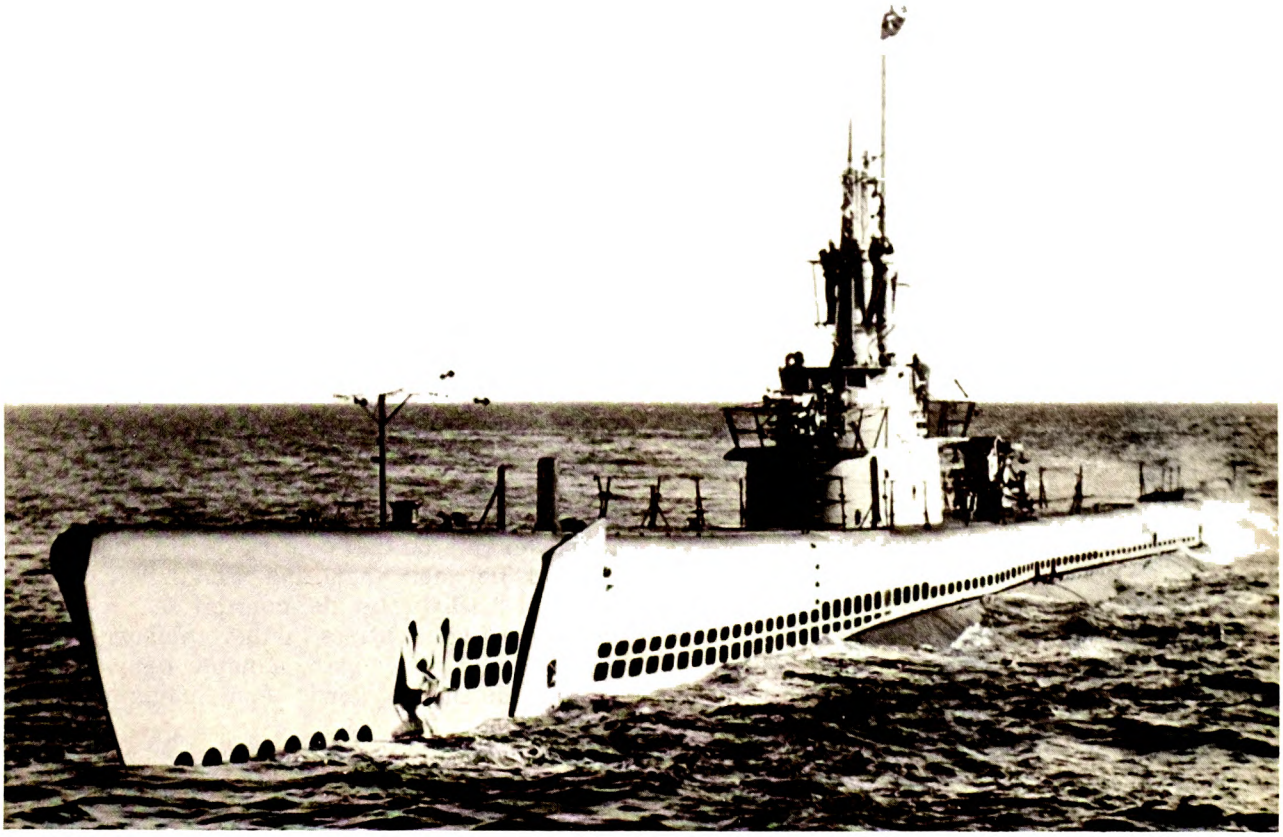

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Figure 11A2.—World War II fleet-type submarine.

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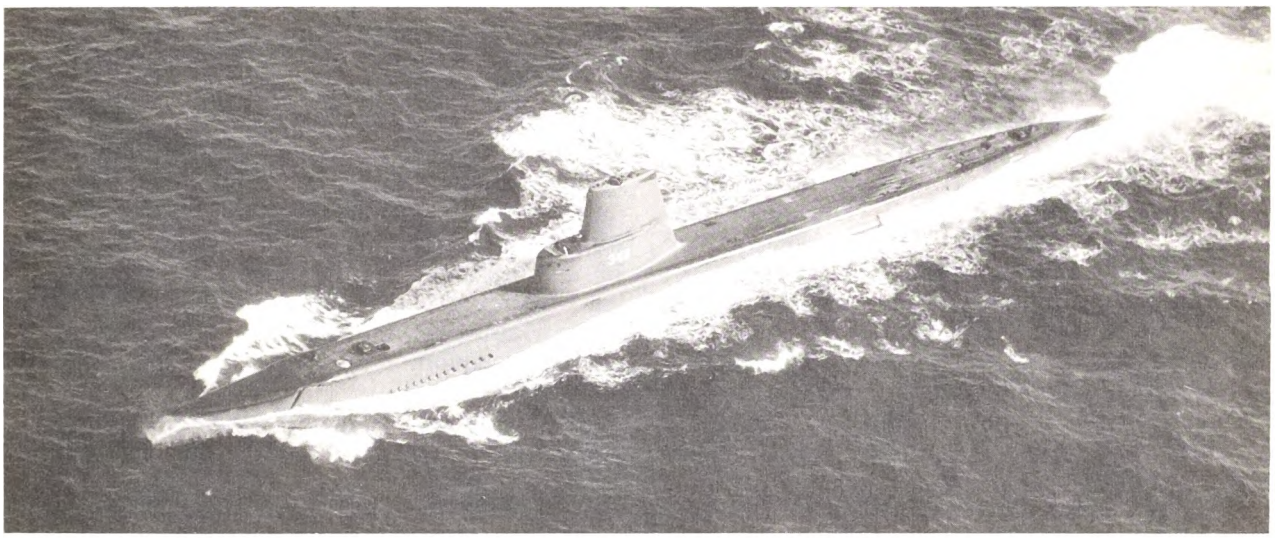

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Figure 11A3.—Guppy submarine.

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Figure 11A4.—USS Nautilus (SS(N) 571).

11A4. THE SOVIET MENACE

Soviet submarines can in many respects be compared to American types. The Soviet submarine fleet consists of about 400 submarines, most of which are modern, long range units constructed during a massive postwar building program. This program increased steadily after 1950 and reached a peak construction rate of nearly 100 submarines in 1956, after which there was a marked slowdown in submarine construction. It is probable that the

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Soviets had reached their desired numerical goal and shifted emphasis to improving the quality and strategic capabilities of the submarine force.

The total threat posed by the Soviet submarine force is increasing steadily. This is because the older submarines being phased out have a marginal capability under conditions of modern warfare. The new submarines, which include a growing number probably capable of launching ballistic missiles, as well as new conventional attack types, are a vastly more dangerous threat. The Soviets probably now have in operation a number of nuclear submarines. Thus it is reasonable to suppose and realistic to anticipate that A/S forces opposing them will find the Soviet submarine and its weapons far from backward technologically.

11A5. SUBMARINES: ADVANTAGES AND DISADVANTAGES

As seen by A/S forces on the surface, the submarine has the following advantages:

1. Concealment. The submarine is of course concealed when submerged and is hard to detect because of its low silhouette even when surfaced. A snorkeling submarine or a submarine at periscope depth is visible to a surface or airborne observer, and shows up on radar, but if the sea surface is at all agitated such detection quickly becomes marginal or impossible. Except in certain unusually transparent ocean areas (in localities of the Pacific and Caribbean, for example) a completely submerged submerged submarine is totally invisible to the surface or airborne observer armed only with optical aids and radar. It can be detected by sonar, but this method has severe limitations, as will be brought out later.

2. More highly trained and developed personnel, both physically and professionally. In virtually all the navies in the world submarine personnel are selected for their superior potential and proficiency, and receive more training in submarine operations than the average naval officer or enlisted man receives in ASW.

3. Passive detection capabilities. Because submarines are so hard to detect, A/S forces must search actively for them, and in the two chief methods of searching, they reveal themselves to the submarines in searching. A radar pulse from a searching A/S vessel can be detected by a sensitive ECM receiver at a much greater range than that at which a submarine's silhouette (or its even less obtrusive antenna, periscope, and snorkel) will return a definite echo. This is particularly true when weather is poor or the sea surface is agitated. A sonar pulse similarly can be heard by a submarine much beyond the maximum range at which the sonar will produce a reliable echo. Lastly, although a submarine snorkeling or on the surface can be seen by surface or airborne A/S observers, usually an observer in the low-lying submarine will see the A/S observer first.

4. Immunity to surface water. A submerged submarine avoids the buffeting of rough surface winds and waves.

5. Reduced noise production. Other things (such as type of listening gear, screw rpm, speed through the water, etc.) being equal, a submarine listening at moderate depth will probably hear a surface vessel before the surface vessel can hear the submarine. At present, the main reason for this is cavitation produced by rotation of the ship's screws in the water. (This phenomenon is explained in the next chapter.) As water pressure increases, cavitation and the noise it produces decrease. A submerged submarine is under greater pressure because of its depth, hence it produces less cavitation noise. It is also true that an electric drive inherently is likely to be somewhat quieter than a steam turbine or Diesel plant, and that conventional submarines generally run at lower speeds submerged than they do on the surface, so that they tend to be quieter even without taking cavitation into account. Recent hydrodynamic investigation indicates that the bow wave (the "bone in a ship's teeth") produced by hull movement on the surface is inherently more wasteful of power, hence noisier, than movement of water around a Skipjack type hull structure completely submerged in the water. Nuclear-powered boats do create more underwater noise than the electrically driven conventional submarines. Speed and depth capabilities partially compensate for this, however. It seems relatively safe to predict, therefore, that the noise-detection advantage that submerged submarines now have is likely to continue in the future.

6. Speed. With the advent of Nuclear-powered submarines and Skipjack type streamlining, A/S craft no longer hold a speed advantage over the submarine.

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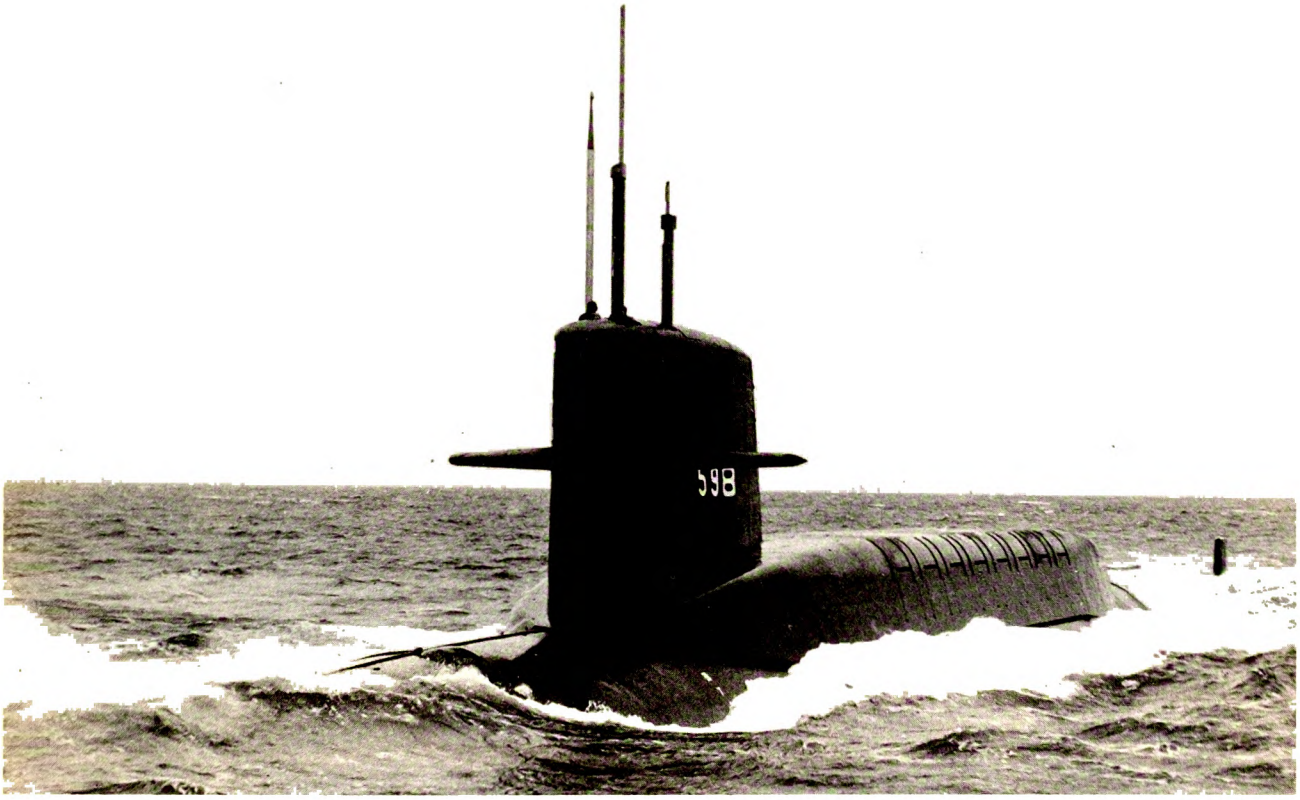

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Figure 11A5.—USS George Washington (SSB(N) 598).

Not all the advantages are with the submarine. In the following respects the A/S forces have the advantage:

1. Variety of Weapons. As will be brought out later, submarines can be attacked with torpedoes, mines, rocket-propelled weapons, missiles, and of course gunfire. Depth charges and hedgehogs are still employed on some of our older A/S craft. Submarines at present have only torpedoes in their antisurface arsenal. Fleet ballistic missiles (Polaris) would not normally be used against an attacking A/S force.

2. Vulnerability. Even relatively slight damage to a submarine can force it to surface—relative, that is, to the damage required before a surface ship is put out of action. Slight damage that does not force it to surface may increase its noise output (for example, it may be necessary to start pumps because of a leak) and give its position away to listening A/S observers.

3. Personnel endurance. This is limited by the physical conditions of life aboard a submerged submarine, particularly of the less advanced types, and the combined psychological and physical strains to submarine personnel under attack by A/S forces, even when the attack is not lethal.

4. Number. A/S forces are generally concentrated so that more than one ship plus aircraft attack a submarine. In theory, two or more submarines can work together in an attack, but any attempt at communication between the submarines will give away their position to the A/S forces, destroying the submarines' main advantage. Moreover, whereas communication between A/S forces is relatively easy (by radio, flashing light, etc.) and cannot be detected by submerged submarines, communication between submarines is at best likely to be garbled and difficult, as well as tactically disadvantageous.

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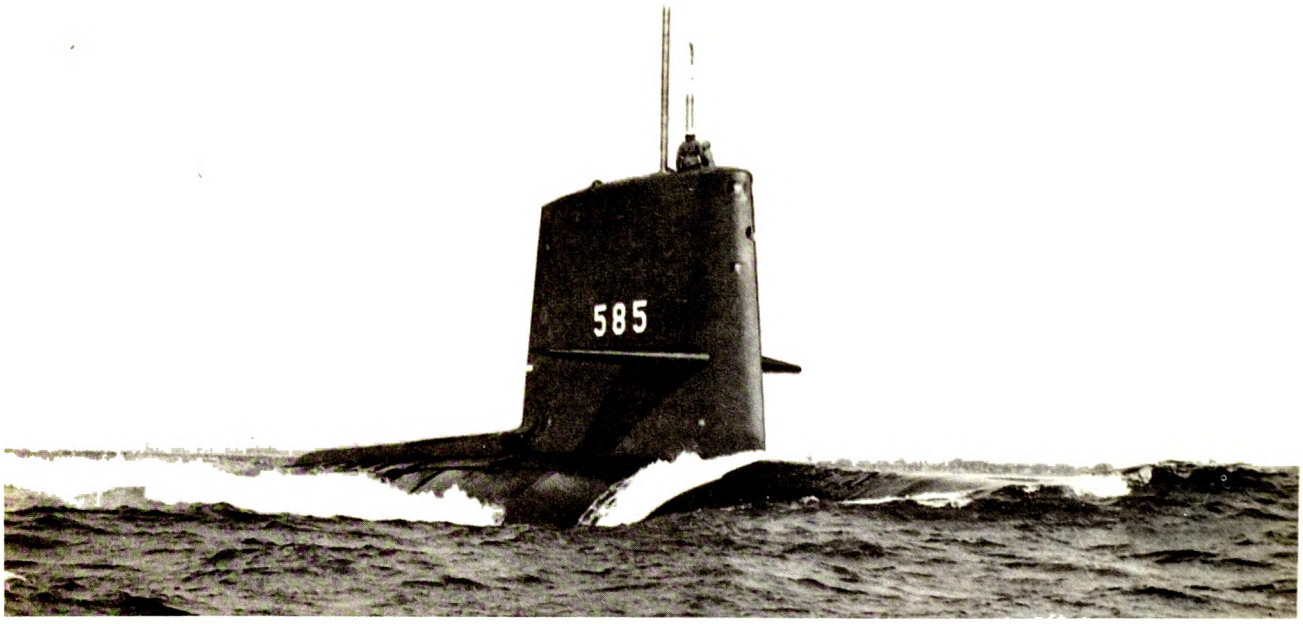

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Figure 11A6.—USS Skipjack (SS(N) 585).

11A6. SUBMARINES AND ANTISUBMARINE WARFARE IN THE FUTURE

No man can say just what warfare will be like in the future, but the outlines that can be conjectured are clear enough to show that naval forces under the sea surface will have much to do with determining who has command of the sea. Based on past experience and on new developments, submarines will likely be used in any or all of the following ways by both sides:

1. To destory the enemy's navy and merchant marine.
2. To impede or cut off the flow of supplies and troops by threat of attack on merchant shipping.
3. To deny use of shipping lanes and harbor areas to the enemy's merchant shipping and naval units by submarine-planted mines.
4. By causing the enemy to concentrate on antisubmarine warfare, to divert him in greater or less degree from his primary mission of winning the conflict.
5. To mount direct attacks by submarine-launched guided missiles and rockets.
6. To function as pickets.
7. To function as transports in situations where the submarine's special characteristics are important.
8. To function as antisubmarine units.

Though in many respects the antisubmarine warfare of the future will resemble that of World War II, there will be great differences. The advent of nuclear-powered ships and submarines, and nuclear weapons creates a growing challenge in the antisubmarine warfare problem of our modern Navy. Detection equipment and tactics are constantly undergoing revision and improvement in order to keep abreast of this changing technology.

Our present A/S ships, such as the destroyer, are formidable adversaries against any submarine. The destroyer can remain at sea for extended periods of time. It carries the latest sonar, electronic countermeasures (ECM), and communication equipment, plus the weapons to go with them and the facilities for reloading under long-endurance wartime conditions. Not only can the destroyer defend itself against enemy attack, but it also can screen and protect other units.

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11A7. MISSION OF ANTISUBMARINE WARFARE

In the words of NWP 24(A), Antisubmarine Operations, "the basic mission of antisubmarine warfare is to deny the enemy the effective use of his submarines". This is a broad mission, and includes not only A/S operations but also operations against their supporting forces, operating bases, and construction facilities.

ASW can be considered as having offensive and protective phases. Offensive tasks associated with ASW include destruction of enemy submarine bases, repair facilities, and construction facilities; the prevention of enemy submarine movement from place to place; the destruction of submarines enroute to and from their operating areas; and the destruction of enemy submarines in their operating areas. (The distinction between these last two is important operationally.) Protective tasks associated with ASW include establishment of operating methods which will ensure safe arrival of shipping at destination, and protection of ships and shore installations against submarine attack.

Operations utilized to accomplish the offensive tasks include A/S strike operations and hunter-killer (HUK) operations. Protective operations include naval control of shipping, A/S escort operations, A/S screen operations, A/S support operations, and A/S harbor and area operations. Operations that may be protective, offensive, or both include A/S mining operations, A/S search operations, and A/S patrol operations. Note that offensive operations may be protective in purpose; there is no need to make too sharp a line of demarcation between offensive and protective.

In this chapter we are primarily concerned with A/S weapons and associated fire control and detection systems, rather than with operations as such, but operations will be discussed to the limited extent necessary to explain the use of A/S equipment.

11A8. INTRODUCTION TO THE PROBLEM OF A/S ATTACK

Now that we have surveyed the outlines of the A/S problem and in general terms compared the capabilities of the adversaries, submerged versus surface and airborne, we are ready to investigate (still in general terms) how, from the point of view of surface A/S forces, the underwater target can be (a) located and (b) attacked.

We have elsewhere in this book discussed methods of locating and attacking surface targets. When it is surfaced, the submarine is a surface target and it is therefore not necessary to discuss further how a surfaced submarine is attacked, except to point out that on the surface a submarine is most vulnerable. It can be most easily detected, is most unprotected, and even if only slightly damaged it cannot submerge. That is why U.S. naval doctrine holds that deck guns, which are a disadvantage underwater because they reduce underwater speed, have little value on the surface, and all of them have been removed. (Submarines of other navies often retain them, however.)

To deal with a submerged submarine, it is first necessary to detect it, establish its location and its rate of movement in bearing and depth, and then solve this fire control problem to predict its future location so that an A/S weapon can attack it. When more than one weapon is used, the problem must be solved for each.

Since with all A/S weapons the time that elapses from the instant of firing to the instant when the weapon actually reaches the predicted position of the submarine (this lapse is called the blind time) is much greater than that for gun and rocket fire control, A/S weapons must be designed to be effective even though they miss the target by much greater margins than, say, gunfire at the same range.

The chief method of detection and location of submerged submarines by surface craft is by using sound, which is transmitted underwater about four times as fast as it is in air. Magnetic methods can be used by aircraft, but at present they are not adaptable to use in surface vessels. Other methods that may be under development cannot be taken up in this book. The primary method of sound detection, sonar, is the main subject of the next section.

Though at present underwater target detection and location by surface craft is done by one method (sonar) to the virtual exclusion of others, a variety of weapons can be used to attack the target.

To the extent that security classification makes possible discussion of A/S weapons in an unclassified textbook, these weapons are taken up in section C of this chapter.

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Section D discusses the way in which the sonar equipment and weapons under the control of the fire control system work together to sink the submarine target, and briefly explains the principal types of A/S attack by surface ships.

The last section of this chapter briefly takes up ASW tactics.

B. Sonar and Other Underwater Target Location Systems

11B1. INTRODUCTION TO UNDERWATER TARGET DETECTION BY SOUND

Echo-ranging equipment is installed on board ships to determine ranges and bearings on submerged submarines by means of sound waves. To a lesser extent, it is used for navigation purposes. In pilot waters, especially in low visibility, it may be used to locate reefs, other submerged objects, and buoys. Echo-ranging equipment is commonly referred to as sonar.

When sound waves impinge on any submerged or partially submerged object, some of their energy is reflected in the manner of an ordinary echo. In active sonar, a sound pulse is projected and, in turn, the echo is received by means of a transducer which is usually located in the water forward and on the keel of the A/S vessel (fig. 11B1). The signal-receiving and indicating equipment (the so-called stack or sonar control indicator) is located in a space known as sonar control. The signal-transmitting equipment, requiring no operator, is generally installed in a space immediately above the transducer.

The principal sonars in use during World War II projected a narrow beam of sound into the water, and target indications were returned as audio responses from a speaker or headset. A thorough search was a slow process in which the operator hand-trained the transducer in increments of 2-1/2° to 5°, according to search doctrine in force. (This was the "search light" type sonar.)

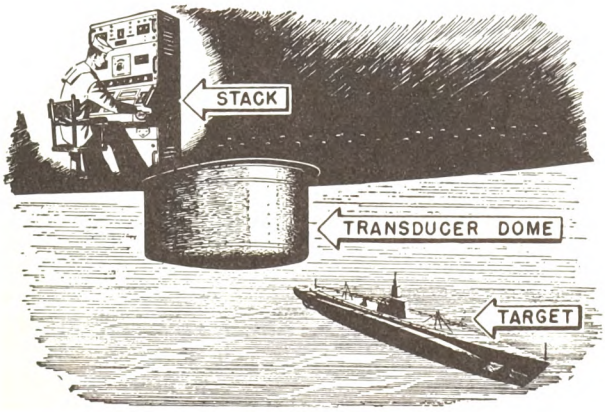

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Figure 11B1.—Elements of sonar system.

At the close of World War II, the Navy perfected a new type of search sonar known as scanning or azimuth search sonar. With each outgoing burst of sound, azimuth sonar reaches through 360°, (except for a narrow sector allowed for the ship's baffles). In addition, scanning sonar offers both video and audio presentation of target information.

The performance of sound waves when transmitted through sea water is a complex study in itself. However, a knowledge of certain features of this subdivision of physics is important in understanding how sonar is used. These are:

1. Speed of sound variations. Temperature and, to a much lesser extent, pressure and salinity differences cause variations in water density which, in turn, cause variations in the speed of sound in sea water. This results in varying values of sonar range which must be taken into account since sound-ranging sonar, like radar, measures range by the time interval between transmitting a pulse and receiving an echo. In addition, variations in sound transmission speed cause the sound beam to be refracted or bent as it passes through the water. This is discussed separately below. The speed of sound in sea water at temperature 39°F, and at normal conditions of salinity and atmospheric pressure is approximately 4800 feet per second. Any increase in pressure or salinity will result in only slight increases in the speed of sound. Any increase in temperature however, will result in an appreciable increase in the speed of sound.

2. Sound beam refraction. As mentioned above, the variations in speed of sound caused by temperature produce refraction of the sound beam. This refraction, unless corrected for, can

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result in serious errors in the measurement of sonar range, and a reduction in detection range.

3. Attenuation. Sound waves propagated through sea water are attenuated rapidly; hence the range at which detection is possible by sonar is reduced.

4. Echoes. Echoes, both single and multiple (reverberations), are received from marine life, the sea bottom, surface disturbances, and various irregularities in the fluid medium, as well as from submarines.

Although adverse water conditions may limit range and make bearing definition difficult, A/S personnel are trained to get optimum results from their equipment under all conditions. They are trained to predict sound behavior and to apply the results reliably to the antisubmarine problem. Sonarmen quickly classify a contact by its appearance on the cathode-ray scope, the quality of the sound, the bearing spread, its relative motion, etc. Sonar research has established certain sound "patterns," based principally on underwater temperatures. With the aid of the bathythermograph, (BT) a device for measuring water temperatures down to 900 feet, it is possible to predict the sound pattern and to introduce these data into the sonar system.

11B2. SONAR PRINCIPLES

There are two principal modes of sonar operation. Passive sonar listens only; the sounds it detects are those originating with the target. Active or echo-ranging sonar radiates a powerful brief pulse of sound vibration into the water, then listens for the echo. The term "sonar" without qualification denotes active sonar. Any underwater object that returns an identifiable sonar echo or produces a discrete sound is a sonar contact.

As in radar, the listening device can indicate the bearing of the signal source it hears. In active sonar the returning echo is timed and the equipment can indicate the range to the target. The equipment can display a video presentation much like a PPI-scope, and also produces an audible output. At present, a single sonar system is used to determine target range and bearing.

The video presentation of the echo permits quick, accurate determination of target range and bearing; a Sonarman's trained ear can analyze the audio reproduction of the echo and determine (a) the nature of its source and (b) its movement with respect to own ship. Analysis to determine the nature of the echo or sound source (this aspect of auditory analysis of sonar sounds applies to both echoes and original noises) is based on experience with sounds produced under varying conditions by different kinds of sea creatures as well as different kinds of targets and simulated targets. (A submarine can for example release a quantity of air from a torpedo tube; the air bubbles will return an echo and show up on the sonar video presentation.) In addition, echoes from moving targets have doppler. Doppler is a change in frequency in the echo (as compared with the frequency of the original sonar pulse) from a moving target having motion along the line of sound. (Anyone who has heard the change in pitch of a railway locomotive whistle or horn as a fast-moving train passes a stationary listener has heard a rather obvious example of the Doppler effect, which was named after Christian Johann Doppler, a 19th-century Austrian physicist.) Doppler indicates relative target motion.

In sonar, doppler is a rather subtle effect and its consistent detection and evaluation require an ear highly sensitive to audible pitch changes, plus much training and experience with audibly reproduced sonar echoes. Sonar systems produce sound pulses of very high and often ultrasonic frequency (i.e., frequencies beyond those of normal human hearing). To produce sonar echoes at audible frequencies in the range (in the neighborhood of 800 cycles per second) to which the human ear is most sensitive and can best discriminate pitch changes, sonar systems use beat frequency oscillators to change the frequency of the received echoes to about 800 cycles per second

Equipment designed to function as active sonar can be used passively if desired. Listening devices designed for passive operation only are called hydrophones. (These are normally installed only on submarines, not on destroyers.) Underwater telephones (colloquially called "Gertrude") used for voice communication, also work on sound conduction principles, but are not to be confused with sonar. They are not taken up in this course.

Sonar is the primary means of detecting a completely submerged submarine, and in general it is the only means a surface vessel has of detecting an underwater target. Echo-ranging sonar is the most effective for shipboard use. An echo ranging sonar system consists of a transducer, or dual-purpose sound head for both receiving and transmitting; electronic equipment

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to generate echo-ranging sound pulses; receiver equipment to amplify and change the frequency of the sounds received; a cathode-ray tube to provide a video indication of the received signals; and sound reproducers (loudspeakers and headphones) to reproduce the received signals audibly.

11B3. AN/SQS-4 SONAR SYSTEM: COMPONENTS AND GENERAL OPERATION

The currently used basic type of search sonar equipment is the AN/SQS-4. Although it has been modified (by the AN/SQS-29 to -32 sonar sets) to incorporate the rotating directional transmission (RDT) feature, the SQS-4 is gradually being replaced altogether by newer sonar sets. These new developments will be covered later in this chapter.

The following is a rather detailed description of sonar operation with the AN/SQS-4 sonar system before recent modifications.

The major components (illustrated in fig. 11B2) of the AN/SQS-4 sonar system are:

Sonar transducer.
Switch assemblies (2).
Audio frequency amplifier.
Sonar receiver-scanner.
Signal data converter.
Sonar transmitter.
Capacitor assembly.
Control indicator.
Range and azimuth indicator.
Target signal simulator control.
Sonar test set.
Headsets and loudspeakers.

From the point of view of the general student, not all of these major components are of equal importance. Hence not all of them are described in later articles.

The AN/SQS-4 is a combination of two echo-ranging systems functioning simultaneously. One provides a continuous video display of acoustic reception in all directions. The other provides an audio response of reception on any desired bearing. Both video and audio presentations are used because the target can be more readily tracked from the video image, but more accurate identification (classification) of the target can be made from the actual sound of its echo. The maximum range setting on the equipment is 15,000 yards.

When the system is in operation, a pulse of sound is transmitted periodically in all directions. The video system scans electronically in azimuth for all echoes of the transmitted pulse. The echoes received appear as bright spots on the face of a cathode-ray tube (CRT) in the control indicator. Each spot appears at the correct bearing on the tube and at a distance from the center proportional to the range of the echo. For detailed investigation of any given echo, the audio system is trained to the echo's bearing by a remotely controlled servo system. It has been established in practice that audio is the only means of classifying an echo as submarine or nonsubmarine with optimum accuracy. The video presentation can help confirm the classification, but it is properly used primarily as a ready means of determining target bearing and of tracking the target. On the other hand, audio reception alone does not suffice for smooth, accurate tracking.

11B4. AN/SQS-4 SONAR SYSTEM: TRANSDUCER

The function of the transducer (fig. 11B3) in search sonar equipment is to convert one form of energy to another. To transmit a pulse, for example, electrical energy is fed to the transducer, and there converted to acoustical energy to produce sound. Conversely, when the transducer is set to receive, acoustical energy received by the transducer is converted to electrical energy for use by the equipment.

The AN/SQS-4 transducer is mounted in a sonar dome on the underside of the ship. The transducer for the underwater telephone equipment also is mounted in the dome. The dome provides protection and reduces noise-producing water turbulence about the transducers.

PRINCIPLE OF TRANSDUCER OPERATION. When transmitting a sonar pulse to the water, the transducer is essentially a device for converting an oscillatory electrical input to an acoustic output. When an echo is being received, the transducer functions to convert an oscillatory acoustic input into an electrical output. Functionally, it can be considered the analog of a radar antenna in that it enables the powerful outgoing signal to be broadcast, after which it becomes a sensitive receiving device to receive echoes.

The transducer used in this sonar system functions on the principle of magnetostriction. When certain metals (nickel, in this case) are in a magnetic field, they will change in length slightly, depending on the direction and intensity of the magnetic field. If the magnetic field

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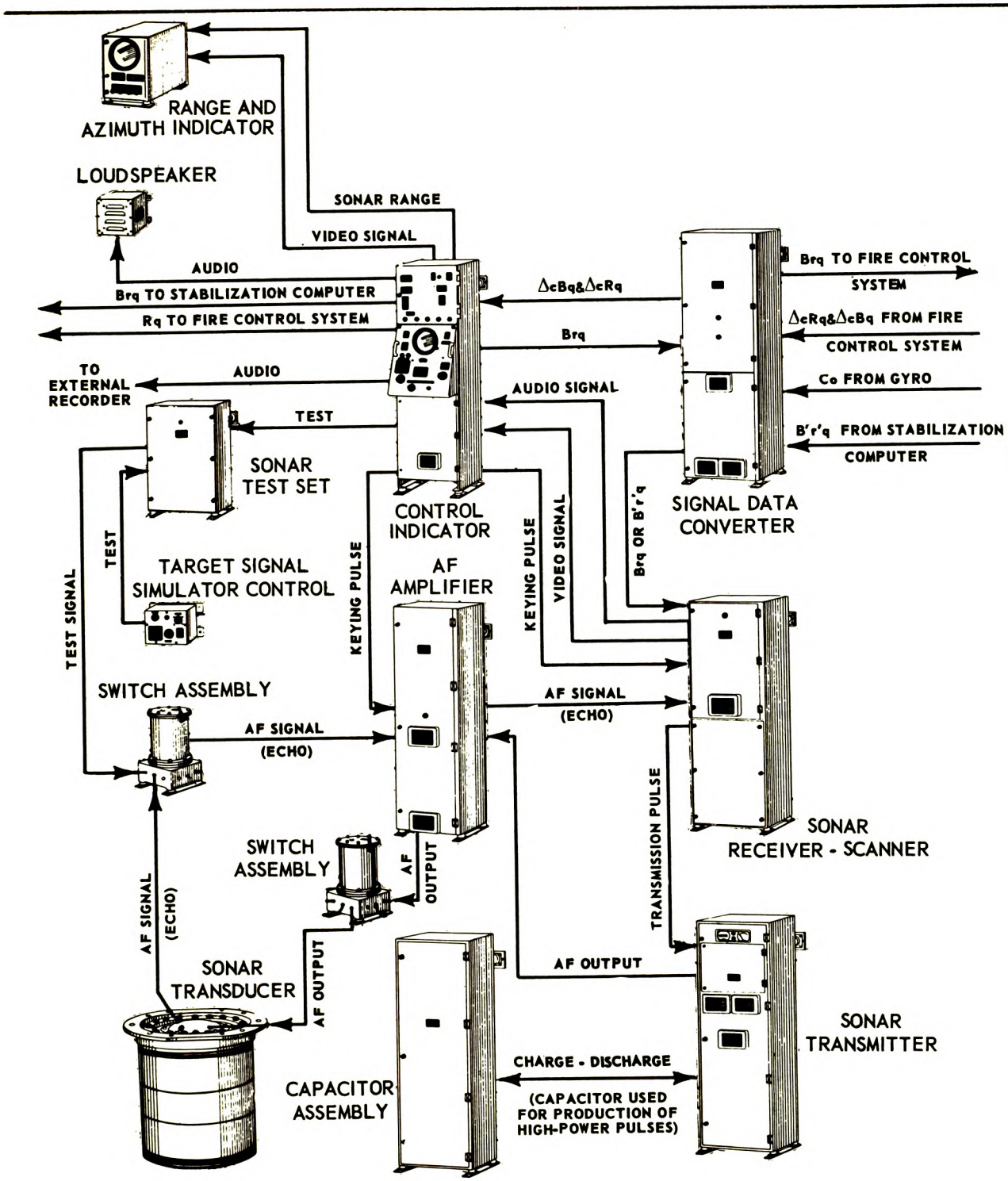

Δ – INDICATES AN INCREMENT OF THE VALUE FOLLOWING THE Δ
c – INDICATES A GENERATED VALUE
SOME AN/SQS-4 COMPONENTS ARE OMITTED FOR SIMPLICITY
COMPONENTS NOT PART OF AN/SQS-4 ARE INDICATED BY LABELS ONLY

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Figure 11B2.—AN/SQS-4 sonar system, Functional schematic.

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changes in direction periodically at a given frequency the metal will change in length in synchronism with that frequency. This is the magnetostrictive effect. This mechanical vibration can be transmitted to the surrounding medium—for example, water. The effect is reversible; that is, vibration picked up from the surrounding medium causes the metal to vibrate similarly, and the resulting change in the magnetic field will induce a voltage in a coil surrounding the metal piece. For transmission of a sound pulse, the coil can be excited by an alternating current of suitable frequency; for reception, the coil can be connected to an amplifier which will amplify voltages induced in it.

This is the principle that is used in the transducer of the AN/SQS-4 sonar system. (Other principles can be used in transducers, but they will not be taken up here.)

11B5. AN/SQS-4 SONAR SYSTEM: OTHER MAJOR COMPONENTS

SIGNAL DATA CONVERTER. The signal data converter's principal function is to adapt the target echoes (video channel) for video presentation so that they will be displayed as blips at the correct bearing and range on the cathode-ray tube (CRT).

SONAR TRANSMITTER. The sonar transmitter develops the high power audio pulse supplied to the transducer when echo ranging. The unit contains the transmitter intermediate and power amplifiers, and their power supplies.

CONTROL INDICATOR. The control indicator (console or stack) is the equipment used by the sonar operator when searching for and tracking submarines (fig. 11B4). It has controls which enable the operator to change range scales, choose the mode of operation, adjust video and audio response, change the bearing for listening, and make certain other adjustments. It consists of a cabinet assembly divided into three stacked sections. The upper two sections are control panels. The bottom section houses the keying chassis and the equipment terminal boards.

RANGE AND AZIMUTH INDICATOR. The range and azimuth indicator is essentially a CRT repeater mounted in a small cabinet assembly. It has two dials which show slant range on the front of the cabinet, a phone jack, and four control knobs. The indicator repeats echo information available at the control indicator. Indicators are installed in the pilothouse and in the CIC of the A/S ship. A speaker is part of the installation also, but if silence is desired at the remote station, it can be switched to headphone operation.

TARGET SIGNAL SIMULATOR CONTROL AND SONAR TEST SET. The target signal simulator control is a control box for the installed sonar test set. These units are used for training, and for equipment testing.

11B6. AN/SQS-4 SONAR SYSTEM: FUNCTIONING IN ACTIVE (ECHO-RANGING) MODE

The functioning of the AN/SQS-4 sonar system in its active mode (the usual type of functioning) can be considered as occurring in four sequential phases: transmission, reception, video presentation, and audio presentation.

TRANSMISSION. The control indicator unit produces a transmission keying pulse. This keying pulse, the length of which is controlled by equipment switching, fires an oscillator which operates at a fixed frequency.

The signal pulse from the oscillator is amplified and sent to the sonar transmitter. In the sonar transmitter, the pulse is further amplified to the high power level required for transmission.

The pulse is converted from electrical energy to acoustical or sonic energy by the transducer. Since the AN/SQS-4 is an azimuth equipment, the transducer transmits the pulse in all directions at the same time.

After transmission of the pulse, the equipment is switched automatically, becoming a receiver.

RECEPTION. When the transmitted sound wave strikes an object, part of the energy of the tranmitted pulse is reflected back to the transducer. The transducer converts received sonic energy into electrical energy. The transducer is broken electrically into 48 different segments during the reception phase of operation. The transducer scanners receive the output of the 48 segments.

The audio scanner is positioned by the operator at the control indicator to a particular bearing. The output of the audio scanner represents all echo and noise sources along that bearing.

The video scanner sweeps the segments continuously at high speed, sampling all echoes and noise sources. The pulses received are fed into video channels, and eventually are presented on the face of the control indicator CRT.

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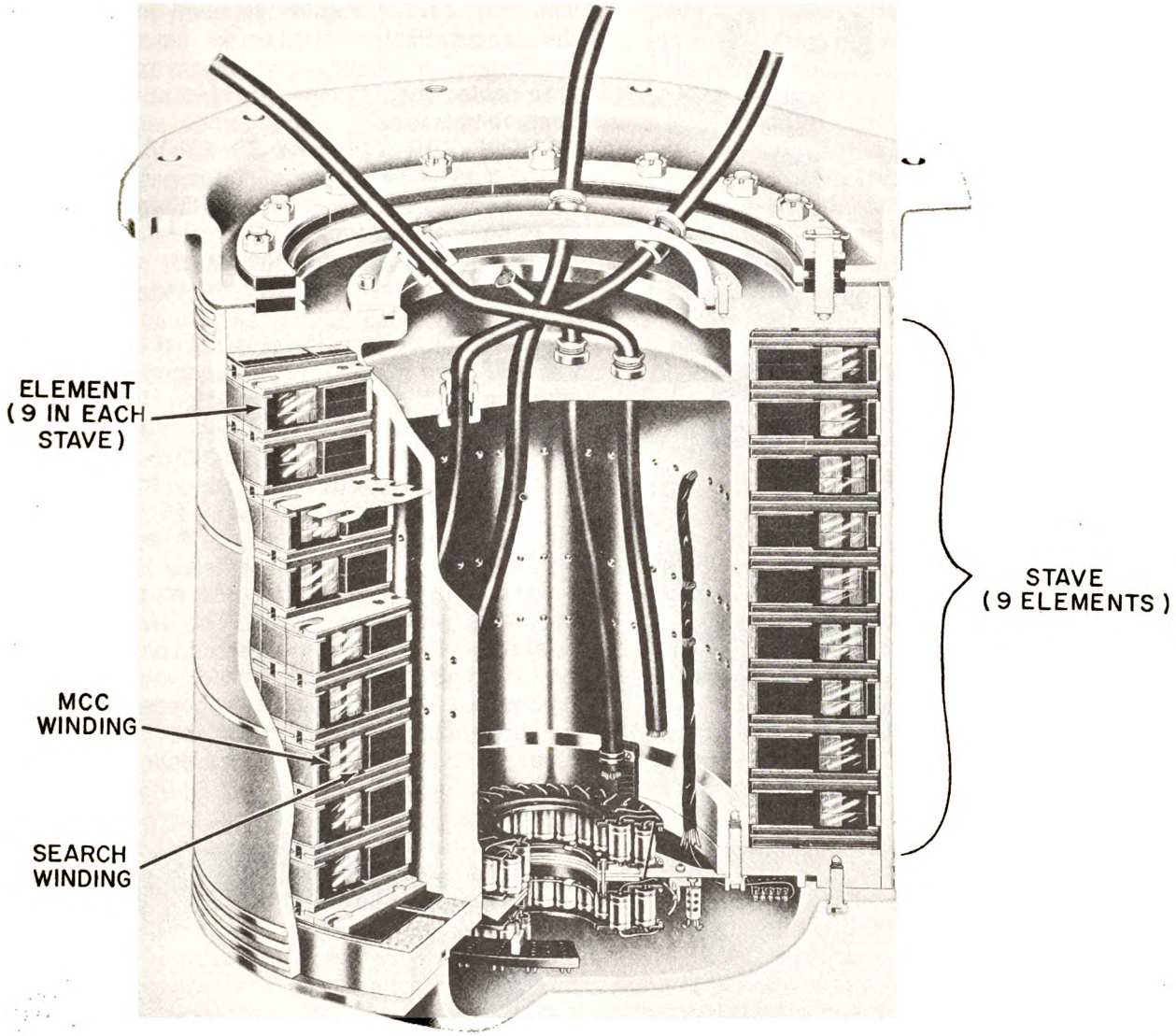

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Figure 11B3.—AN/SQS-4 sonar system. Transducer. Cutaway view.

The time interval between pulse transmission and reception of its echo is a measure of the distance to the object reflecting the pulse. Circuitry in the reception part of the sonar equipment converts this time difference to a distance relative to the range of the object for video and audio presentation.

PRESENTATION. Both audio and video signals are amplified and converted to usable signals by the sonar receiver scanner. The video signals are used for presentation on the control-indicator CRT. Audio signals are built up to a proper level and frequency for loudspeaker reproduction.

The control indicator has controls to select the mode of operation (listening or echo ranging), the echo ranging scale, and whether the display shows the ship or target in the center of the CRT.

11B7. VIDEO PRESENTATION

MODES OF PRESENTATION. The video presentation may be either a (own) ship center

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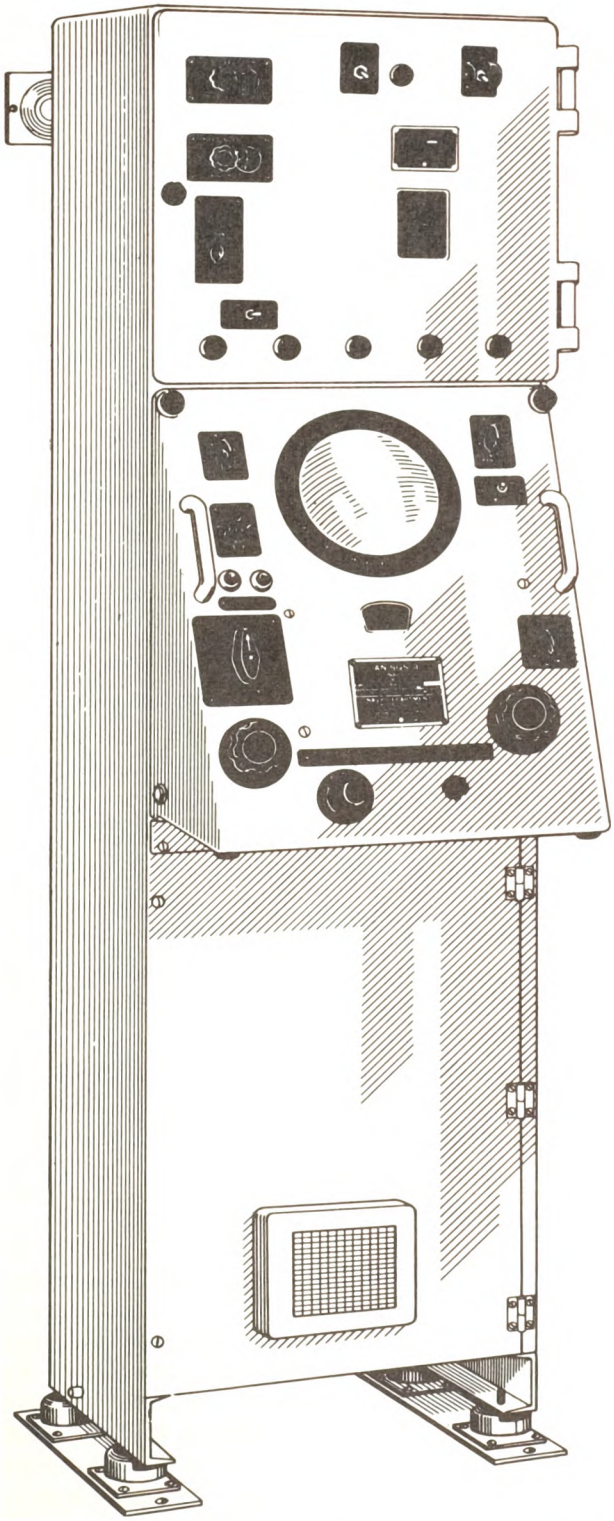

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Figure 11B4.—AN/SQS-4 sonar system. Control indicator.

display (SCD) or a target center display (TCD). The ship center display is used in searching; the target center display is usually used in tracking. The description below applies to the ship center display; the target center display is described later.

HOW THE DISPLAY IS PRODUCED (SCD MODE). The sequence of information as presented on the face of the CRT is automatic. Starting with a blank CRT, follow through one complete cycle (from the start of one pulse transmission to the start of the next). (See fig. 11B5.)

A line or cursor, originating at the center of the CRT, and parallel to the bearing of the audio scanner, is the first presentation. With this the operator can read on a dial around the CRT's face the bearing of echoes he hears.

Immediately following the printing of the cursor on the CRT, the pulse is transmitted. The electron beam appears and begins the expanding sweep at a rate proportional to the time it takes the transmitted pulse to travel. This expanding sweep is spiral. The electron beam prints as it revolves in synchronization with the rotating video transducer scanner. The angular position of the beam corresponds with the instantaneous position of the video transducer scanner. Presence of an echo, therefore,

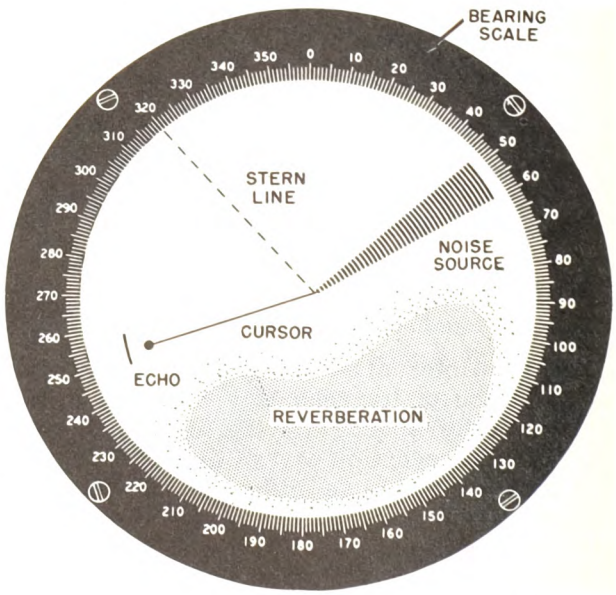

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Figure 11B5.—AN/SQS-4 sonar system. CRT presentation.

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produces a bright spot on the face of the CRT, at a point corresponding to the range and bearing of the object reflecting the pulse.

As the pulse is transmitted, a broken line, originating at the pulse presentation, and bearing 180° from own ship's heading, is displayed. This is known as the stern line, and it assists the operator in determining areas for searching.

Since the equipment is alert in all directions because of the rapid scanning feature, a true geographic plot is produced of the area surrounding the ship. Noise sources other than echoes from the transmitted pulse are received also, and are presented as bright spokes or wedges on the CRT at their correct bearing. The operator can determine range and bearing to a contact by training the cursor to the center of the spot and adjusting its length. The bearing may be read directly from a dial. Cursor length may be varied by a control on the control-indicator. Cursor length is proportional to the range and, when the end of the cursor is super-imposed on the target echo, range may be read from a dial on the control indicator.

When searching for a target, the sonar system is set so that the two video signals (left and right) from the scanner are added or summed. This provides a broad, easily seen blip for an echo. When the target blip has been identified and the sonar system is set to track it, the system is switched for difference operation. The left- and right-scanner outputs are then subtracted, and the target blip becomes small and sharp so that it can be tracked most effectively.

DISPLAY ORIENTATION AND STABILIZATION. The video presentation is normally oriented and stabilized. The top of the CRT represents north. Own ship course is received from the ship's gyrocompass. Bearings to echoes are true. Without gyro input, the presentation is in relative bearing, with ship's head at the top of the CRT at 000°. Changes in own ship course will, when the presentation is in relative bearing, cause the entire CRT picture to rotate. When the presentation is in true bearing, the electron beam in the CRT is electrically rotated to keep the pattern it prints oriented.

The video presentation is also compensated to eliminate the effect of own ship roll and pitch, and keep the CRT picture stabilized.

TCD MODE. In the target center display the contact, instead of own ship, is displayed in the center of the CRT. The expanding spiral sweep presentation is used, but the origin of the sweep (own ship position) is moved to a position off the face of the CRT, and the contact is positioned at the center of the scope.

Only a circular portion of the entire sweep is displayed on the CRT when the contract is in the center, unless range to the contact is within the display limitations of the scope. In that case, both own ship and contact would be presented.

When the contact is in the center of the scope, dials on the control indicator show the range and bearing to the contact from own ship.

The stern line remains with the transmitted pulse for both types of display. It is visible when the equipment is in target center display only when own ship's transmitted pulse comes into display range on the CRT. Most display conditions remain the same for both types of display.

FEATURES OF VIDEO DISPLAY. Figure 10B5 shows the main features of a typical SCD sonar CRT display. (This is a highly conventionalized diagram, and is not intended to show the features realistically.)

1. The cursor, which is printed by the electron beam, is shown as a straight radial line with a spot (to simulate the bright spot in which it terminates) at its outer end. Its length and bearing can be adjusted by the sonar operator; its length is proportional to range. When superimposed on the echo blip, the cursor shows the range and bearing of the echo source on dials on the console.

2. The bearing scale is engraved on a ring dial surrounding the CRT. As mentioned earlier, when the own ship course input is coming into the system from the gyro compass, the CRT display is continuously oriented so that true north is at the top (zero point) of the dial, and the cursor and stern line positions can be read as true bearing. When gyro input is not available or is shut off, the display is oriented for relative bearing (zero at the top of the dial).

3. The stern line, painted by the electron beam, is a line from the center of the CRT to the edge, and corresponds to the bearing of ship's centerline from the sonar dome toward the stern. The bearing it indicates is 180° off from ship's heading.

4. The target blip, or echo pip, is a bright spot on the tube face, painted by the electron beam at a position on the tube corresponding to target position in range and bearing. When the control indicator is set for sum indication of the two video signals, the target blip is relatively broad and easy to spot. For accurate indication of its bearing, the video presentation is set to

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difference; the spot decreases in size and may lose brightness, but its bearing can be determined much more accurately.

5. Reverberation or minor sound reflections from such sources as surface waves, small fish and other sea life, etc., shows up as small spots or light patterns.

6. Noise sources, as distinguished from echoes (either random or from specific targets), show up on the CRT as radial spokes or wedges rather than blips. Sonars are responsive to a wide range of frequencies; unlike radar, a sonar is not tuned to receive a specific frequency. It therefore picks up all kinds of noise sources. This is called hydrophone effect, and it occurs during active mode operation, as well as in passive or listening mode. Since the CRT indications of noise sources do not arise from timed echoes of the transmitted pulse, there is no blip that shows range to the noise source. The spoke shows only bearing. The spoke can be made broad or sharp by sum or difference reception.

There is no video indication of doppler in the AN/SQS-4 equipment.

11B8. AUDIO PRESENTATION

The returning echo, after conversion to an electrical signal and amplification, is changed to an audible frequency and sent to a headset or loudspeaker near the control indicator, where it is heard as a "ping." This ping is of value in target identification and in the determination of doppler.

The outgoing (transmitted) pulse from the sonar is so far as possible suppressed so that it does not show on the CRT or become audible on the sonar's sound reproducers. To determine whether the pitch or frequency of the echo has been changed by the doppler effect, the sonar operator compares the echo aurally not with the original pulse but with the reverberation return, since the average reverberation source is moving at zero speed. (The sonar circuitry electonically compensates for doppler effect in reverberation caused by own ship speed; therefore, doppler depends upon only relative target motion toward or away from own ship.) Since acuity of pitch discrimination varies with frequency, a frequency is selected in the region where human ears are most sensitive to pitch changes—around 800 cycles per second (equivalent to a note in the upper range of the piano keyboard).

Up doppler is the increase in frequency of returning sound waves caused by a target's motion toward own ship. Down doppler is the decrease in frequency of returning sound waves caused by a target's motion away from own ship. A target which causes up doppler is said to have bow aspect, while a target causing down doppler has a stern aspect. A beam-aspect target has no doppler.

11B9. AN/SQS-4 SONAR SYSTEM: FUNCTIONING IN OTHER MODES

FUNCTIONING IN LISTEN MODE (PASSIVE). Presentation on the CRT when in listen mode consists of a sweep that occupies the outer half of the CRT, and a bearing cursor and two bright spots aligned to the train of the audio transducer scanner. The transmitter does not function in this mode.

UNDERWATER COMMUNICATION. The AN/SQS-4 sonar may be used for CW (continuous-wave code) underwater communication. A hand key is provided on the control indicator for this purpose. The selector switch must be in listen for utilization of this feature. Because of the terrific power drain on the transmitter, a very slow rate of transmission must be used. Because of this limitation, and because of the inconvenience of CW transmission as compared with voice transmission, this method of underwater communication is a secondary means.

11B10. AN/SQS-29 TO -32 SONAR SETS (MODIFICATION TO AN/SQS-4)

The AN/SQS-29 to -32 sonar sets are the result of modifications to the AN/SQS-4 omnidirectional type of sonar. The Sonar Set AN/SQS-4 has been modified to provide a feature of rotating directional transmission. After modification, the nomenclature changes from Sonar Set AN/SQS-4 to Sonar Detecting-Ranging Set AN/SQS-29, -30, or -32.

The addition of rotating directional transmission to the conventional scanning sonars (AN/SQS-4) in use today has greatly increased the effectiveness of antisubmarine warfare. In the past, conventional scanning sonar used only the omnidirectional type of searching. In other words, it scans equally in all directions. If the total power to this omnidirectional pulse is concentrated into a narrow sector, greater power of transmission results, and improved sensitivity and ranges are realized. This RDT

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system provides a source level improvement that is inherent in directional transmission. It produces a maximum level of sonification in a narrow, selected bearing, directional beam.

11B11. AN/SQS-23 SONAR SET

The AN/SQS-23 sonar set greatly increases the capability and versatility of shipboard mounted sonars. Accurate range and bearing information, with ranges greater than those obtained on previous equipment, is provided for the fire control system. The low transmission frequency of the equipment, combined with rotating directional transmission (RDT) and the ability of the transducer to operate at a tremendous power-output level, produces a high source level for long-range target detection. As can be seen, the AN/SQS-23 is a great improvement in search-attack sonar equipment.

11B12. VARIABLE DEPTH SONAR (VDS)

One of the problems affecting the ability of sonar to detect and maintain contact with a submarine is the layer depth in water. It has been proven that one of the best methods of overcoming this obstacle is to position the transducer below the layer where it can operate without this deterent. As a result, the variable depth sonar (VDS) (fig. 11B6 and fig. 11B7) was designed and produced in an attempt to overcome poor sonar conditions caused by layer depths that interfere with the more conventional types of sonar.

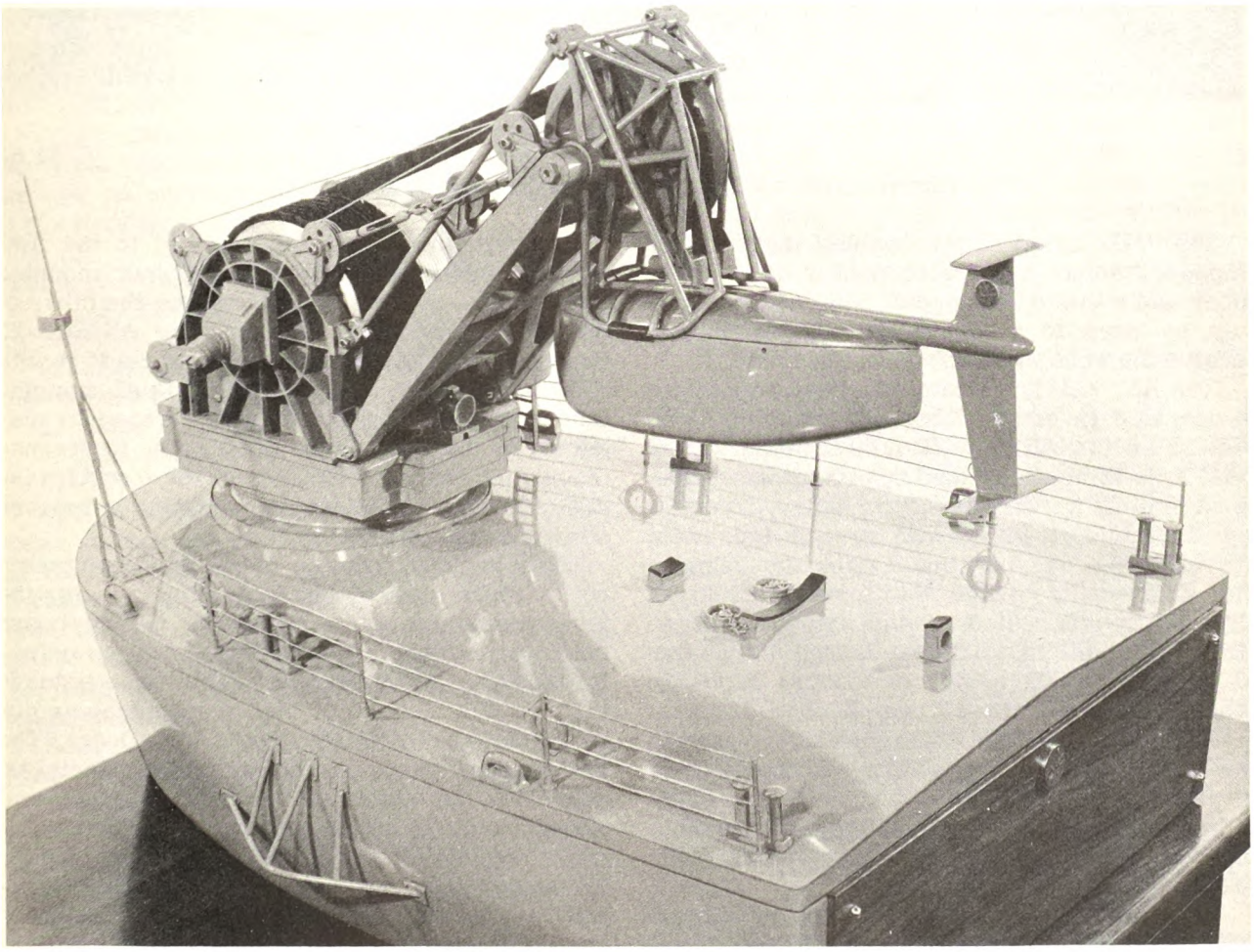

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Figure 11B6.—VDS in saddle, winch facing forward in service position.

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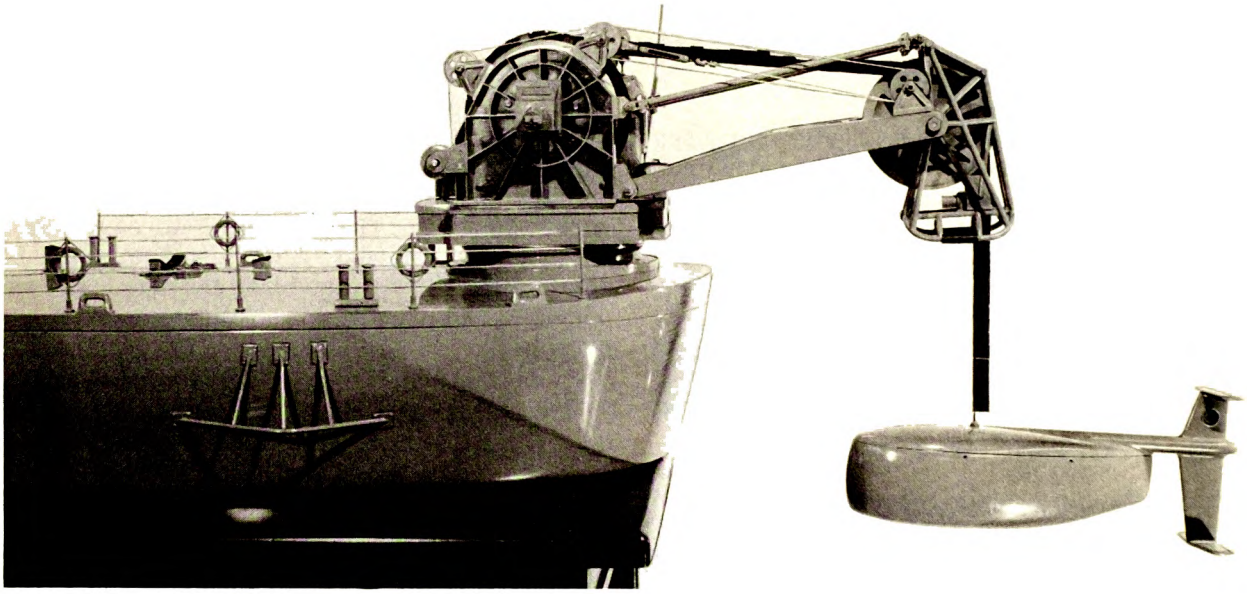

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Figure 11B7.—VDS suspended with boom facing aft.

The VDS modification enables the existing shipboard sonar to operate with a hull transducer and a towed transducer. Either transducer may be used to transmit the RDT beam and receive the echo signals.

The AN/SQS-11 variable depth sonar system is operated in conjunction with either the AN/SQS-23 or the AN/SQS-29 hull-mounted sonar sets. This is accomplished by providing a transducer within a variable-depth, hydro-dynamic, towed vehicle, together with a crane-type hoist for lowering, raising, and towing the vehicle. The transducer inside the towed vehicle is electrically connected to the ship through an electrical cable that extends through the center of the mechanical armor of the tow cable. In general, the AN/SQA-11 may be thought of as a transducer removed from the hull of a ship and towed through the water, separated from its sonar set by a 600-foot tow cable. The depth of submersion maintained by the towed vehicle depends on the length of cable payed out and the speed of the towing ship.

The existing shipboard sonar equipment (AN/SQS-23 or AN/SQS-29) performs its normal transmission, receiving, and interpretive display functions unchanged by the addition of the towed transducer.

A switching mechanism added to the AN/SQS-29 permits it to use its hull-mounted transducer, or employ only one or the other of the two transducers. The existing AN/SQS-23 requires only minor changes to provide it with VDS capabilities. It also can use its hull-mounted transducer simultaneously with the towed transducer, or only one or the other of the two transducers. Operating frequency of the towed transducer is derived from the existing shipboard sonar equipment.

The general function of the VDS equipment is to make use of the pulsed power for the transmission of sonar signals by the shipboard sonar equipment. This pulsed power is transmitted via the electrical cable that extends through the center of the mechanical armor of the tow cable to the towed transducer. The transducer, operating on acoustic principles, converts the electrical energy to acoustical energy and transmits it to the surrounding water. When the transmitted sound wave strikes an object with adequate reflective characteristics, a portion of the total energy is reflected back to the towed transducer. The direction of the echo indicates the bearing of the object. The transducer then converts the acoustical energy of the echo into an electrical signal, whose

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magnitude is determined by the intensity of the received echo. This electrical signal is transmitted up through the tow cable to the AN/SQS-23 or AN/SQS-29 for display and interpretation.

11B13. AN/SQS-26 SONAR SET

The future success of the U.S. Navy in maintaining control of the seas will depend to a considerable extent on its ability to cope with high-speed nuclear submarines.

Immediate and compelling, then, is the need for submarine detection capabilities at significantly increased ranges, with reliable performance independent of the water characteristics of any particular operating area.

To fulfill this task, the AN/SQS-26 sonar has been developed. It is a long-range, advanced search sonar that represents a radically improved approach in concept and in application to the present-day problems of submarine detection. Detection features and operational flexibility of the AN/SQS-26 permit long-range coverage independent of water conditions and the depth and speed of the target. It is designed for use on surface ships to detect submarines at great ranges.

11B14. AIRBORNE SUBMARINE-DETECTING SYSTEMS

Aircraft are used for detecting submerged submarines by—

1. Sonar.
2. Sonobuoys.
3. MAD.

SONAR. Sonar equipment (called "dipping sonar") can be used by rotary-wing aircraft (helicopters) to detect submerged submarines. Because it isn't practical to drag sonar equipment through the water at the minimum flying speeds of fixed-wing aircraft, only aircraft that can hover or move at low speeds are suited for sonar detection.

Because of the limited weight-carrying and power-producing characteristics of aircraft, high-powered azimuth type sonar is not carried by aircraft. The equipment is of the "searchlight" type which pings on one bearing at a time, must be trained to the required bearing to detect a target, and presents only an audible echo without video presentation. In spite of these limitations, airborne sonar gear is capable of excellent results because it can be transported from one location to another at a much higher speed than that of any surface vessel, and because, although such aircraft as helicopters are noisy, they produce no water-conducted noise. (Most dipping sonar presently used in helicopters is capable of scanning 360° and also of narrowing the search to a selected bearing.)

In a helicopter, the dip or dunking sonar equipment, all except for a ball-shaped transducer housing and the 90-foot cable from which it is suspended, is located in the helicopter fuselage. When the helicopter has reached a location where the presence of a submarine is suspected, it descends to 10 to 20 feet above the water, and the sonar ball is lowered to about 60 feet below the surface. After searching, the helicopter hauls in the cable. After the cable has been retracted, the helicopter can go to another location. When the submarine is detected and located, the helicopter can "vector in" other aircraft and A/S vessels for the attack, or can itself attack if it is carrying homing torpedoes such as the Mk 43 or depth bombs.

The search procedure can be completed in a few minutes (especially if the search doesn't encompass the full 360° in azimuth) and the helicopter can be up and away. Present types of submarines have no effective countermeasures against helicopters. This search technique is much more difficult in heavy weather, although improvements in this respect are being made continually.

Figure 11B8 shows a helicopter with sonar submerged, searching.

RADIO SONOBUOYS. Radio sonobuoys are small expendable floating hydrophone or sonar units whose output is radio-broadcast on FM by a small transmitter in the sonobouy. They are generally dropped to the sea surface by fixed-wing aircraft in the area where enemy submarines are expected to be. Usually more than one is dropped at a time, in a circular pattern around the contact area (as determined by other detection data). An experienced operator, by comparing its pitch (for doppler) as received by each sonobuoy, can estimate the present location and direction of movement of the target. After two to four hours, a soluble plug in the sonobuoy dissolves and allows the unit to sink. While afloat, the sonobuoy indicates its position visually (by releasing red dye into the water or by keeping a lamp lit) and by radar.

Figure 11B9 shows diagrammatically how one type of sonobuoy pattern is initiated by an aircraft in response to surface indication of the presence of a submerged submarine (in this case

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Figure 11B8.—Dip sonar in use by helicopter.

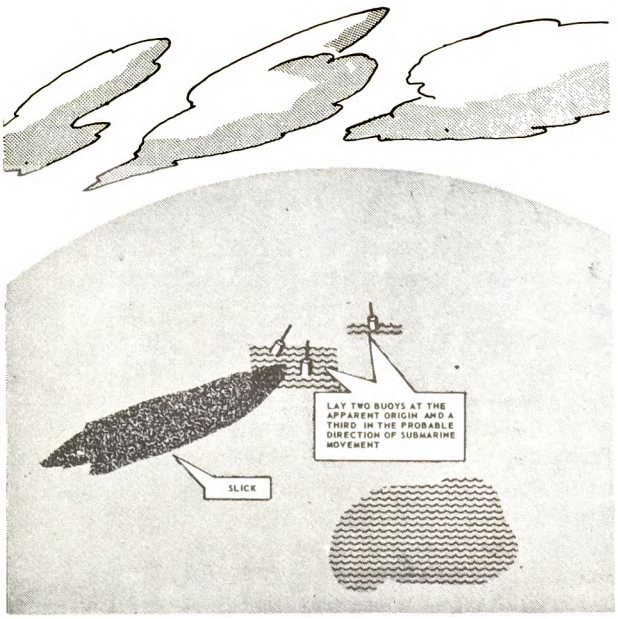

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Figure 11B9.—Radio sonobuoys used to locate submerged submarines.

the oil slick from a submarine that has been damaged). The buoys are planted where they will continue to pick up the submarine's sound as it proceeds underwater. A frequent pattern is a circle of buoys about the area (called the datum) in which the submarine contact is expected.

MAD. MAD stands for Magnetic Airborne Detection. Any mass of steel as large as a ship's or submarine's hull will significantly warp or distort the earth's magnetic field in the vicinity. In influence-type exploder devices in mines and torpedoes this effect is used to detonate the device when quite close to the target. For locating a submarine at a greater distance than this, the same principle is used but the device is more sensitive and must be moved at a relatively high speed with respect to the target. MAD equipment is therefore used, as figure 11B10 indicates, on fixed-wing aircraft flying at relatively low altitudes.

11B15. SUBMARINE COUNTERMEASURES

Submarines can and do take specific countermeasures against surface ship and aircraft

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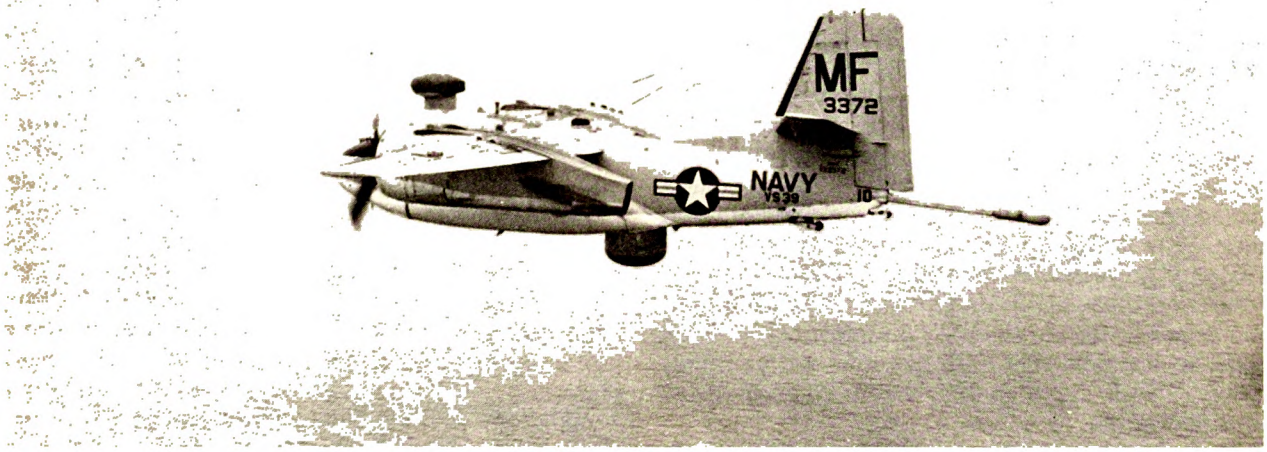

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Figure 11B10.—A/S fixed-wing aircraft fitted with MAD gear.

detection and attack. Some of these countermeasures are similar to those taken by surface ships; these won't be repeated here. Others are designed to make the submarine harder to detect on sonar or hydophones. Still others are intended to deceive or confuse the attackers. In either case, the result (if successful) is to make the attacker lose contact with his target.

The list below includes the principal types of countermeasure that submarines can now use.

SUBMERGING. This is the primary natural defense of the submarine against detection. There are several degrees of submerging, from running with deck awash, to snorkel depth (running with the snorkel, periscopes, and antennas just above the water surface, but with the entire superstructure submerged), to periscope depth (with only the attack periscope protruding from the surface), to shallow submergence (about 60 to 100 feet), to deep submergence (at a maximum or "test depth" for the submarine). A snorkeling conventional submarine can continue to run on Diesels and charge its battery. Although it presents a reduced target to visual and radar search, its propulsion machinery is at its noisiest. At any speed exceeding a couple of knots the protruding parts develop a wake that grows proportionately more noticeable with speed, particularly if the water is smooth. And in very cold weather the Diesel exhaust through the snorkel forms a plume of white vapor. When the submarine is slightly deeper, at periscope depth, the periscope by itself is much harder to spot than the snorkel and associated gear, but it and its wake are still detectable, even if marginally, to radar and eye. At shallow depths (down to 100 feet or so) a speeding submarine does cause noticeable turbulence on the surface, if the sea is relatively calm, and its hull can sometimes be spotted visually by aircraft. When the submarine is deeply submerged, its presence is rarely betrayed by any evidence on the surface.

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Where the sea bottom is not deep, a submarine can rest on the bottom next to a wreck, reef, or turbulent area to present virtually no target to echo-ranging sonar.

SILENT RUNNING. To avoid detection by hydrophone, submarines must reduce noise radiation as much as possible. Chief sources of noise are echo-ranging sonar, operation of propulsion machinery (particularly Diesel engines), operation of other machinery such as ventilating gear and pumps, cavitation produced by rotation of screws above certain critical speeds, and screw noises from other causes (such as deformed blades). A submarine commander can order any of several degrees of silent running, ranging from reduction of running speed and shutdown of echo-ranging sonar to complete stoppage of all machinery and even prohibition of the crew's talking above a whisper. Silent running conditions are ordered, of course, only when the submarine is submerged. A submarine snorkeling or running on the surface under Diesel power is at least as noisy as any similarly powered surface vessel. Electric drive at the same speed is much less noisy. Nuclear submarines, as previously mentioned, are as noisy or noisier than conventional submarines; however they are capable of running at much greater depths.

A submarine running silent can still attack by releasing a "swim-out" homing torpedo against a surface attacker. Firing a conventional torpedo is a noisy procedure that requires forcing a large air bubble out of the torpedo tube along with the torpedo. A "swim out" homing torpedo propels itself out of its tube, runs upward to set depth and begins to search for its target (while the submarine dives), and homes on the surface ship's screw noises. (Homing torpedoes are discussed in the next section of this chapter.)

USE OF THERMOCLINES. A previous article has explained how the path of sound waves in sea water is distorted by differences in water density. Submarines are fitted with recording bathythermograph units which function whenever the ship dives, so that the presence of thermoclines is continuously indicated. The submarine can dive under a thermocline and in most cases cause the attacking vessel to lose contact entirely.

The new sonar sets, discussed earlier in this section, make it more difficult however, for the submarine to use a thermocline as a countermeasure.

HIDING BENEATH SURFACE VESSELS. Because a sonar is relatively "deaf" in the area directly below it, a submarine can find concealment directly below its attacker. Or a submarine can hide directly below some other ship, using the surface vessel's screw noises and turbulent wake to mask its own sonar echo. In this position the submarine can use swim out homing torpedoes, as described earlier in this article.

FALSE TARGETS. A mass of air bubbles is detected by sonar as a target. Submarines can eject air through their torpedo tubes to create a false, target for the benefit of surface sonar. The target doesn't last long, and it betrays its nature to a sharp Sonarman because it has no doppler, but it can distract the attacker long enough to cause loss of contact. A German-originated device specifically designed to eject bubbles for this purpose was called the "Pillenwerfer," and the name is sometimes used to refer to similar devices on our own submarines.

Another type of false target is the beacon. This is a small battery-powered screw-propelled torpedolike device that can swim out of a torpedo tube and continue running until its battery runs down. It emits a continuous or intermittent noise simulating a submarine's screws, sonar pings, or other sounds. A number of different sounds can be produced. After ejecting this device, the submarine usually heads downward and in the opposite direction, while the beacon moves at 1 or 2 knots in the direction in which it was projected. A beacon not only distracts passive sonar search, but also can attract A/S homing torpedoes intended for the submarine.

Submarines can also eject quantities of oil and debris to simulate their own destruction, and thus motivate surface attackers to call off the attack.

NOTE ON COUNTERMEASURE EMPLOYMENT. In practice, the effectiveness of the countermeasure in deceiving the attacker, and the ability of the attacker to penetrate the deceptions and maintain contact, depend principally on the tactical ingenuity of each side. Earlier in this chapter you studied the principal advantages and disadvantages of the submarine vis-a-vis the surface attacker. In ASW each combatant makes the most of his advantages (including psychological ones), and does his best to overcome the other's stratagems. The variations and combinations possible are endless. ASW has been called a "cat-and-mouse" game. This is not entirely accurate, since the "mouse" is as dangerously armed as his opponent, but in

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two respects the comparison is apt—one successful blow is likely to decide the issue; and, in contrast to open combat between air and surface opponents, patience and watchfulness over a prolonged period are likely to be the decisive factors.

C. A/S Weapons

11C1. INTRODUCTION

The weapons used in antisubmarine warfare are probably of more varied types than those in any other branch of naval warfare. They, like other weapons, have changed radically during recent years. Thus A/S weapons may now be broadly categorized into old and new types.

1. Old types
   a. Depth charges
   b. 7.2-inch projector charge (hedgehog)
   c. 12.75-inch rocket (weapon alfa)
   d. Homing torpedoes (older types)
2. New types
   a. Homing torpedoes (newer types)
   b. Dash
   c. Asroc
   d. Subroc
   e. Astor

These weapons will be discussed in this order throughout the following paragraphs. It is important to remember, however, that because A/S weapon development is progressing with such rapidity, possibly even some of the new developments included in this chapter will soon be declared obsolete. The Navy has placed a high priority on ASW; thus many new developments can be expected in this field.

11C2. DEPTH CHARGES

Depth charges (abbreviated D/C) are thin-walled containers filled with a heavy charge of explosive and designed to explode at a predetermined depth or by the action of an influence fuze. They have a teardrop shape, tail fins, and a weighted nose, to increase sinking rate and improve underwater trajectory. They contain about 200 pounds of TNT or HBX. (Fig. 11C1.)

The depth at which explosion will occur is controlled in the older hydrostatic type by setting a hydrostatic (water pressure detonated) exploder mechanism which is graduated to 600 or 1,000 feet (in different mods). In the newer influence type, explosion is initiated by an influence-type firing mechanism which arms hydrostatically. Neither type depends on contact with a submarine. It is extremely difficult to obtain a direct hit with depth charges, because the exact position of the submarine usually is not known. Consequently, depth charges depend on the percussive wave of the explosion for their effectiveness. The effective radius of the percussive wave depends upon the structural strength of the attacked vessel, and no definite values can be stated, but to be fatal the charge probably must explode within 20 feet of the target.

At the outbreak of World War II, the primary A/S weapon was the depth charge. The advantage of this weapon against the then current slow and awkwardly maneuvering submarine was notable.

Because of its high explosive content, the depth charge had a larger lethal radius than any other A/S weapon in use. It retained this advantage even after being replaced by the hedgehog as the primary A/S weapon.

A corresponding advantage is the adverse effect of the depth charge attack on the submarine crew. Because the weapon has high explosive power, and because it will detonate without contact (even if there is a miss), the resulting explosion still will work to demoralize the crew.

Another advantage resulting from the high explosive force of depth charges is the probability of visual evidence of damage. During World War II, a primary method of evaluating submarine damage was the sighting of oil slicks, clothing, and the like, floating on the surface.

Depth charges are still part of the A/S armament on our older destroyers; however they are rapidly becoming obsolete throughout the fleet. The high speed and maneuverability of modern submarines render the D/C ineffective as an A/S weapon.

11C3. HEDGEHOGS

A throwing weapon in general use today is a mortar-type projectile called the hedgehog. It has a body 7.2 inches in diameter and carries 30 pounds of TNT or Torpex. It is propelled forward by an impulse charge and explodes only on contact. In other words, it has no depth

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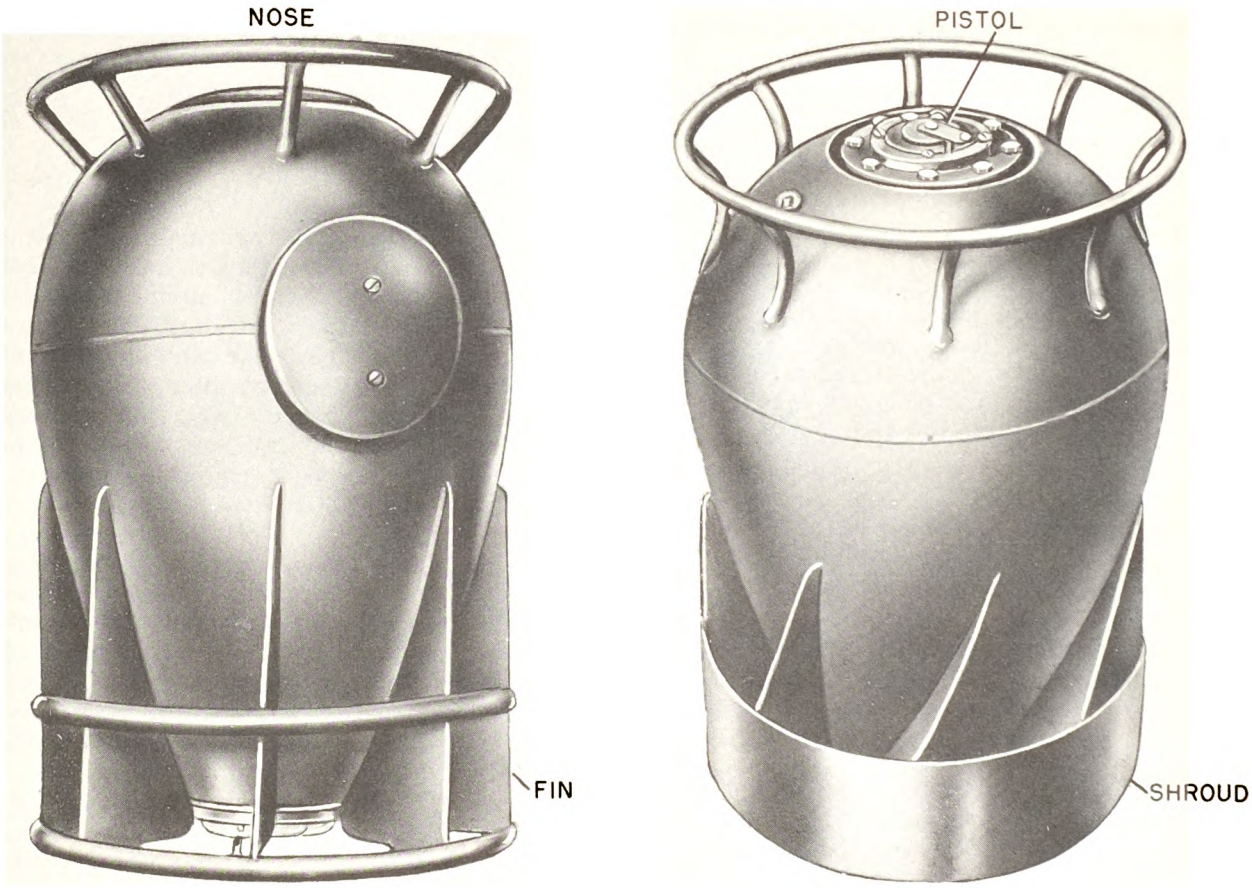

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Figure 11C1.—Depth charges.

setting, and does not detonate by passing near the target—it must score a hit to explode.

The 7.2-inch projector charge looks like a rocket. It has a tail tube (which looks like a rocket motor), fins, and a shroud. (See fig. 11C2). However, this missile is not a rocket.

Hedgehogs are fired electrically in groups of 24 charges from each mount (fig. 11C3). Charges are fired in pairs, and intervals between pairs are about 1/10th second. The 12 pairs of charges are fired in a total time of 1.0 to 1.5 seconds.

For a ship to attack a submarine with hedgehogs, contact must usually be held with the submarine up until time of firing. Ranges and bearings are converted to target motion by fire control instruments that indicate the course along which the ship must be steered and the time when hedgehogs must be launched to score a hit. Because the charges have a fixed range, the pattern must be launched when the ship reaches the correct firing range. Correct firing range depends on many factors, such as our own ship's speed, range rate, target motion, and so on.

Figure 11C4 shows loading operations for the Mk 15 mount. Note that the tail of the hedgehog is placed over a spigot, which contains a firing pin.

Each row of spigots is mounted on an athwarships beam or cradle that can be tilted fore and aft. Tilting the cradles results in a slight change of elevation, which is used to compensate for roll and pitch but not to vary the range. There is a power drive for training the projector mount, and an additional elevating power drive to tilt the cradles.

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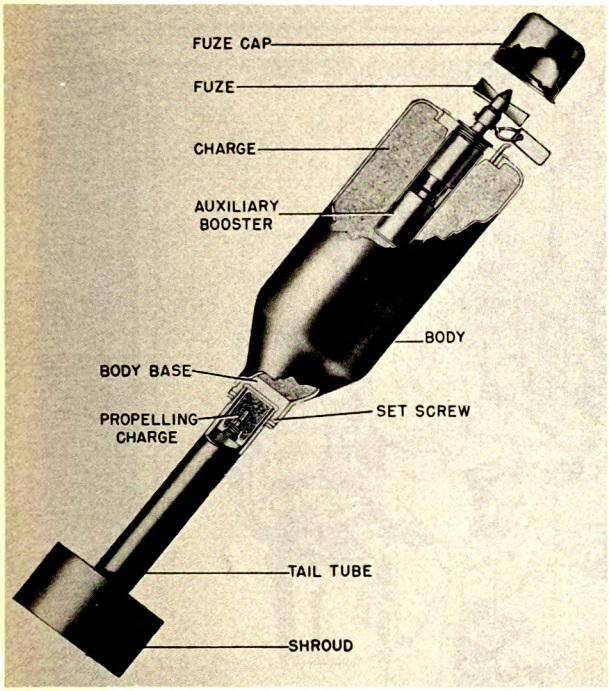

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Figure 11C2.—7.2-inch projector charge. Cutaway view.

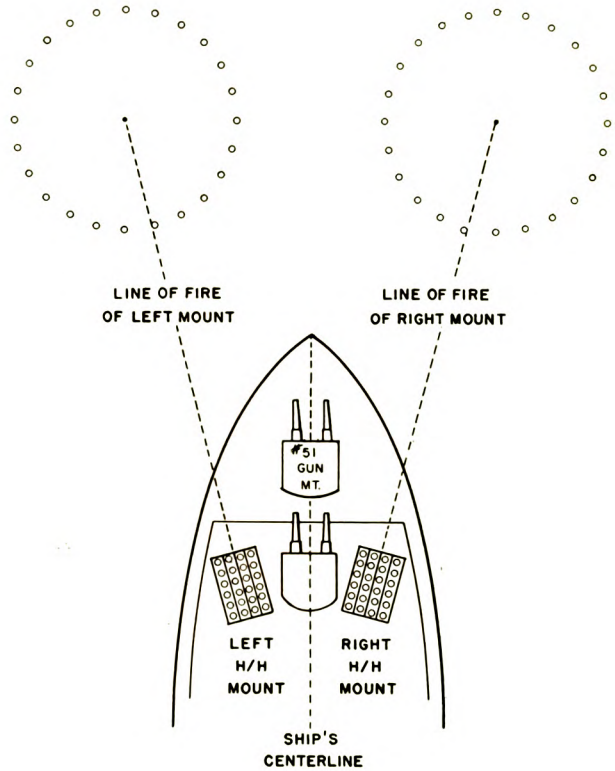

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Figure 11C3.—Pattern of fire of a salvo. Not to scale.

The Mk 15 is a development from the older Mk 10 and Mk 11 mount. Cradles on the older mounts are set fore and aft, and tilting these cradles compensates for as much as 20° of train.

All mounts fire the same 7.2-inch hedgehog projectile. When fully loaded, all mounts hold 24 projectiles.

Hedgehogs have many advantages over depth charges. They can be launched before contact is lost at short range, thus reducing to a few seconds the submarine's maneuvering time after firing. The Mk 10 and Mk 11 mounts can, as mentioned, partially compensate for train, while the Mk 15 provides full gun train. In practical terms this means hedgehogs can be trained and fired while the ship is still coming about to the best attack course. Finally, if there is no hit, there is no water disturbance to interfere with echo ranging as will happen with depth charges.

Like depth charges, hedgehogs are becoming obsolete in a Navy which may someday be called upon to combat high speed nuclear submarines.

11C4. 12.75-INCH A/S ROCKET

The 12.75-inch rocket is an antisubmarine projectile, abbreviated ASP but more popularly known as Weapon A. It is a comparatively recent A/S weapon, installed only on larger A/S ships. This projectile is a true rocket, receiving propulsion from a rocket motor. (Fig. 11C5°). It carries a heavier bursting charge than the headgehog and can be fired at greater ranges.

Weapon A is fired from the Mk 108 rocket launcher. (Fig. 11C6 and 11C7.) The launcher magazine holds 22 rounds, which are fired singly at a maximum rate of 12 rounds per minute.

When an armed rocket comes within close range of a submarine, the submarine's effect on the earth's magnetic field causes the mechanism to receive a "look." As the rocket passes the submarine, it receives a reverse look produced by a reverse change in the earth's magnetic field. It is the scond look that causes the rocket to explode.

The 12.75-inch rocket has all the desirable features of the hedgehog, plus increased explosive charge, increased range, and the ability to explode within lethal range without actual

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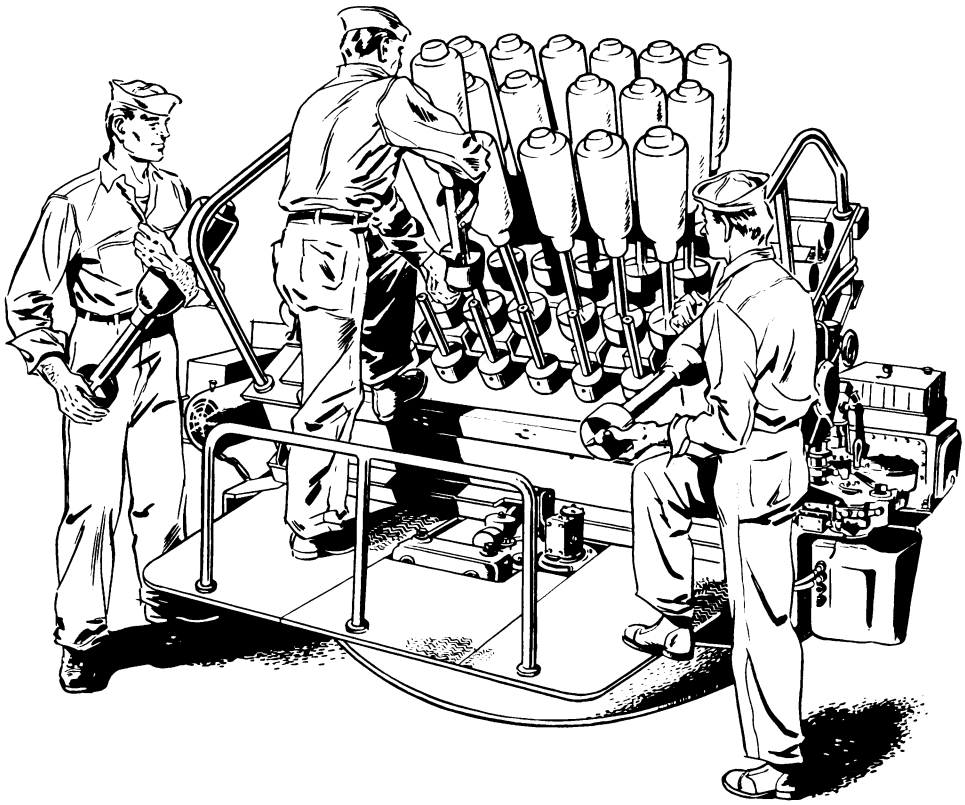

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Figure 11C4.—Loading the Mk 15 hedgehog mount.

impact. Although it is not fired in patterns, as such, the rate of fire gives effective coverage.

Although quite a few A/S ships are equipped with Weapon A, it is gradually disappearing from fleet use.

11C5. A/S TORPEDOES

Many of the A/S ship's weapons include A/S torpedoes. There are various marks and modifications of A/S torpedoes in use today. Some of these are described in the following subsections, and in chapter 10.

TORPEDO MK 32 MOD 2

The Mk 32 Mod 2 torpedo, which is obsolescent although some still are in use, is one of our earliest A/S torpedoes. It is an active acoustic homing torpedo, which detects and attacks submerged submarines through echo ranging. It can be launched from surface vessels.

TORPEDO MK 35 MOD 3

Torpedo Mk 35 Mod 3 is an electrically driven torpedo capable of homing on a target by acoustic control. This weapon is a destroyer-launched torpedo.

Control mechanisms for the Mk 35 Mod 3 torpedo provide for a preenabling run to a position close to a target, followed by a search in a predetermined pattern. During search, the torpedo transmits short pings of acoustic energy to be reflected from the target. When the echoes are picked up, the torpedo homes on the source of the echo.

The preenabling run is similar to the warshot runs of other torpedoes; it is made at a predetermined depth and on a predetermined course. Depth can be chosen at will within the depth range of the torpedo. A typical warshot run is seen in figure 11C8.

Course is controlled by setting the gyro angle, which is the angle between the heading

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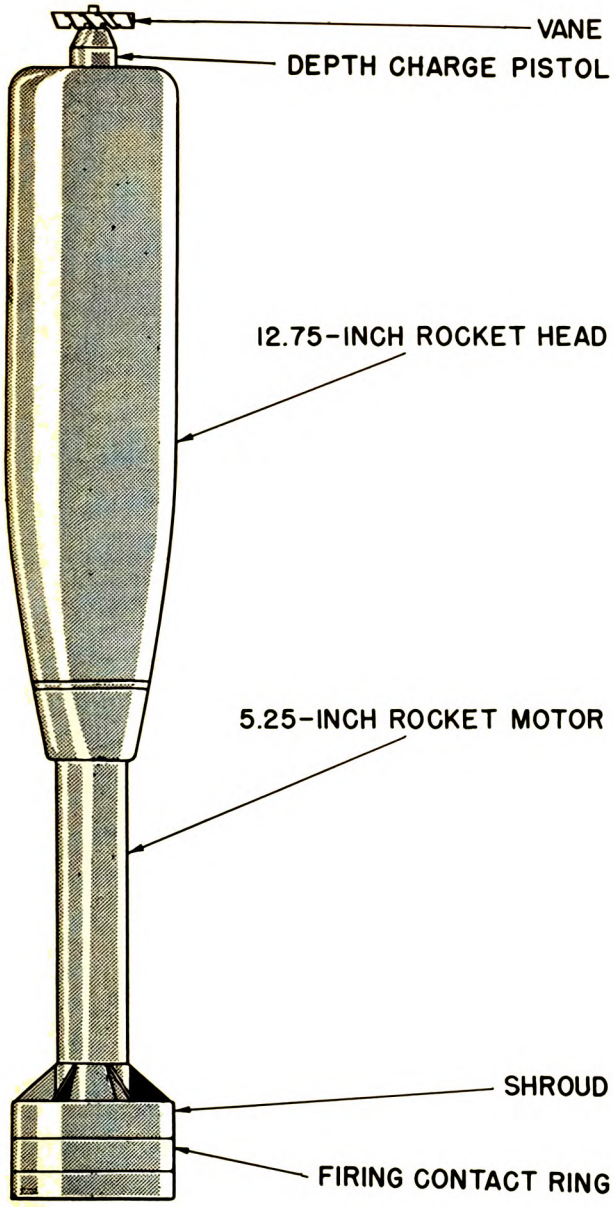

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Figure 11C5.—12.75-inch A/S rocket.

of the torpedo as it lies in the tube and the heading of the calculated course.

Length of the enabling run is controlled by setting in an enabling range that can be chosen at will.

The three settings (depth, gyro angle, and enabling range) are made electrically during the priming period by external means. They are corrected continuously up to the last possible instant before launching. During the preenabling run, the search and acoustic controls are inactive. The preenabling run is calculated to place the torpedo within pinging range of the target.

The search pattern, which begins at the instant of enabling, starts with an initial turn to port or starboard at the depth of the preenabling run. The torpedo then begins to search in depth. The torpedo continues to change depth in the original direction until the limit of its depth range is reached.

At the upper or lower limit, the direction of the vertical search is reversed automatically. The turns are made at a uniform radius, and the vertical search is made with uniform rates of climb and dive. Search in this pattern continues to the end of the run or until the target is picked up.

TORPEDO MK 37 MOD 0

The Mk 37 Mod 0 torpedo is an electrically controlled and propelled two-speed torpedo with an active-passive acoustic homing system. This torpedo is launched from submarines or destroyers, and is effective against either surface or submarine targets. It is launched from above water tubes as an air-ejected torpedo or from submerged tubes as a swim-out torpedo.

TORPEDO MK 37 MOD 1

The Mk 37 Mod 1 torpedo is similar to the Mk 37 Mod 0 except that it has an added feature of wire guidance.

TORPEDO MK 43 MOD 3

The Mk 43 Mod 3 torpedo is a lightweight, small-size, active acoustic homing antisubmarine weapon, which uses the principle of echo ranging to locate and pursue a target. It can be launched from surface vessels and aircraft. The torpedo is capable of searching for, pursuing, and hitting submarine targets that are stationary, or are traveling at low speeds and shallow depths.

When used for a warshot, the torpedo is provided with a warhead that contains HBX and an exploder mechanism. For exercise runs, an exercise head is installed in place of the warhead.

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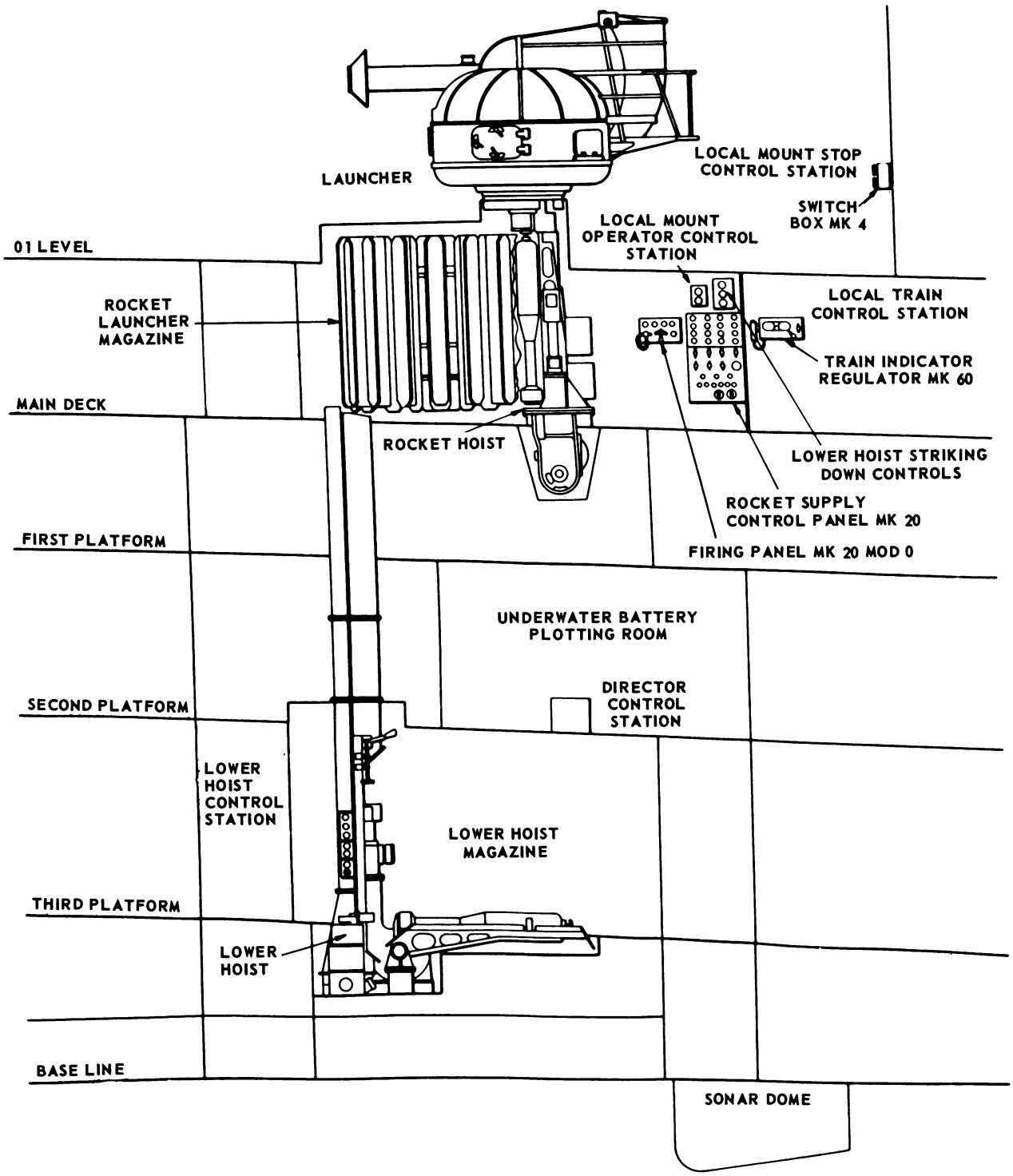

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Figure 11C6.—12.75-inch A/S Rocket Launcher Mk 108. Cross-section.

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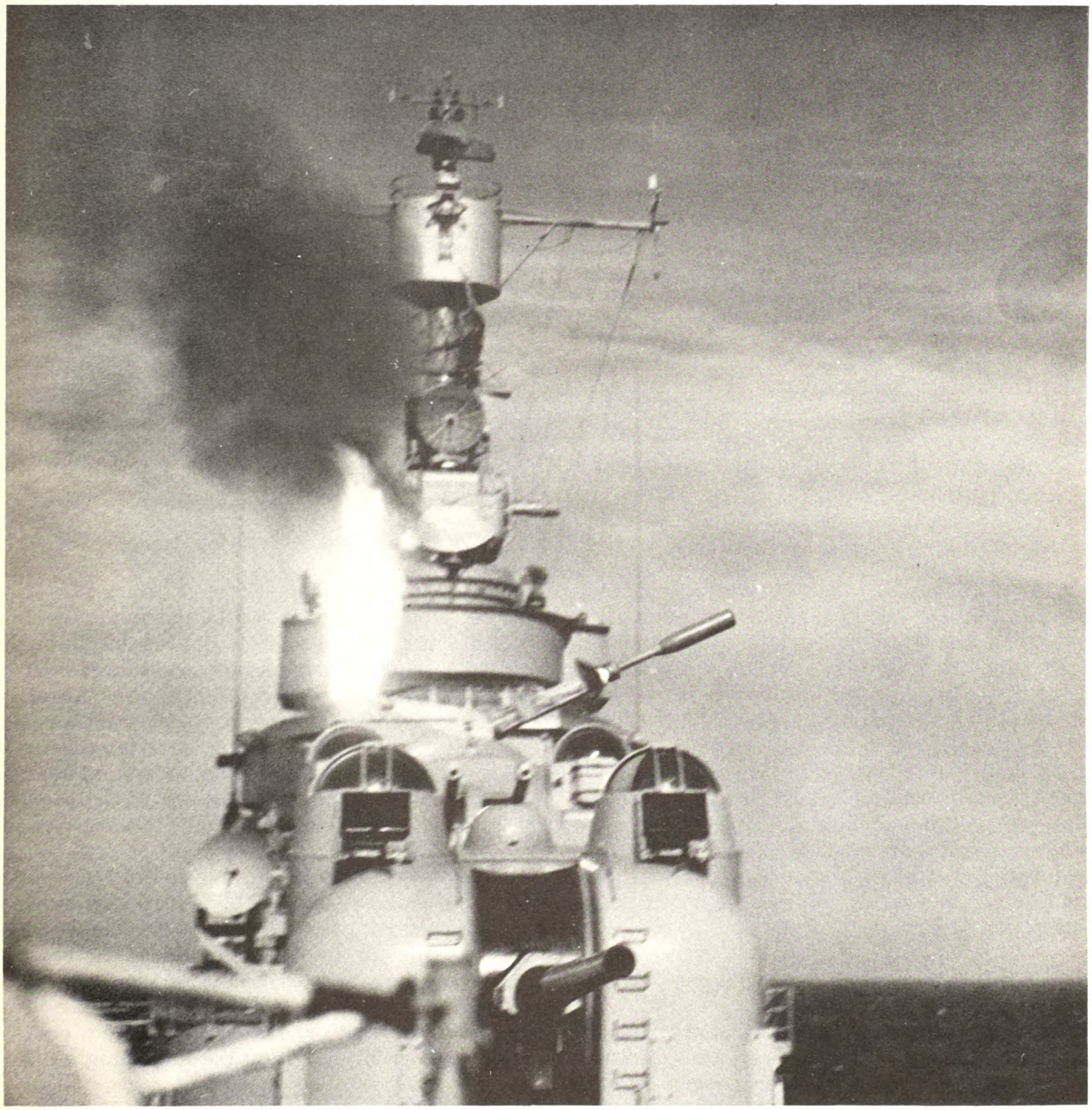

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Figure 11C7.—12.75-inch rocket being fired.

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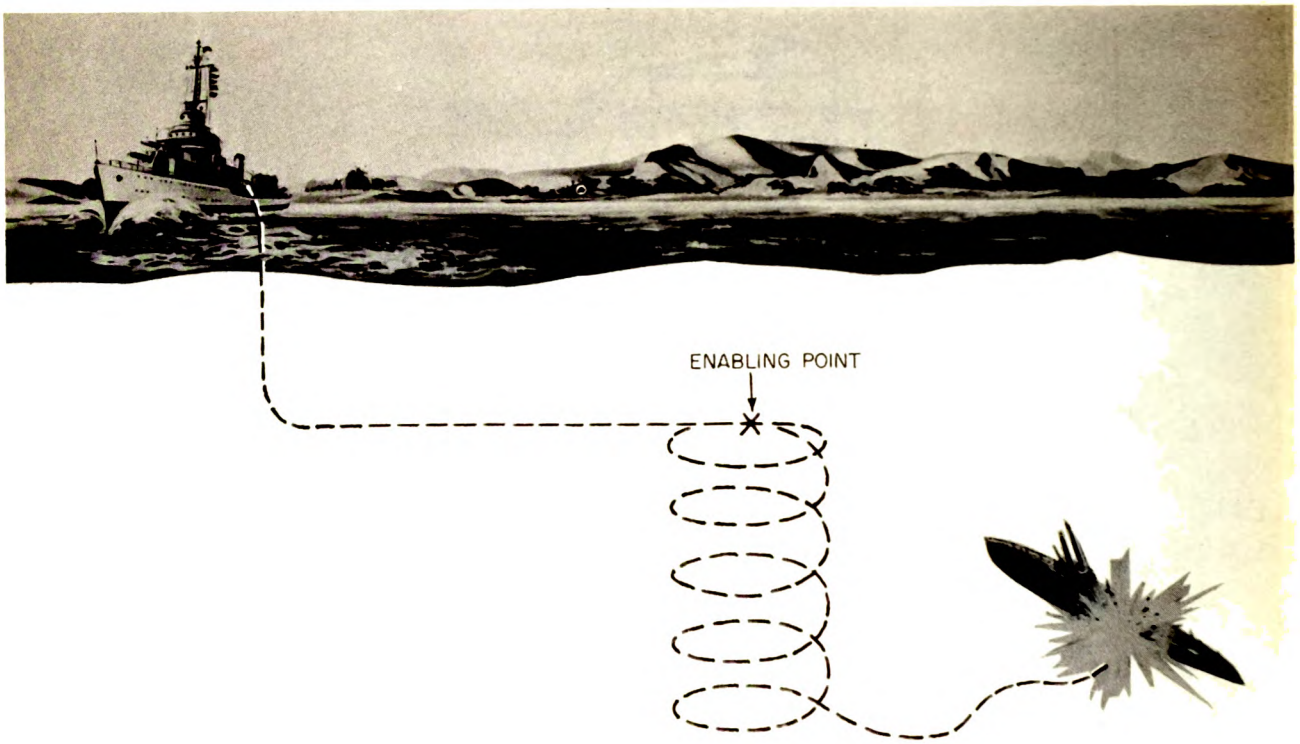

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Figure 11C8.—Typical warshot run of a Mk 35 Mod 3 torpedo.

In operation, the Mk 43 Mod 3 torpedo transmits pulsed acoustic signals while traveling in a search pattern. When a reflected echo is received, circuits within the torpedo are activated and the torpedo is guided toward the target, in a pursuit pattern, until the target is hit or the battery is exhausted. If the reflected signal ceases to be received, the circuits within the torpedo cause a return to search pattern control of the guidance mechanism. This continues until another reflected signal is received, or until the power supply battery is exhausted (in a warshot), or until termination of the preset run time (in an exercise run).

TORPEDO MK 44 MOD 0

The Mk 44 Mod 0 torpedo is an electrically controlled and electrically propelled antisubmarine weapon, with an active acoustic homing system. The torpedo can be launched from surface craft or aircraft.

The torpedo is designed to attack submerged submarines traveling at moderate speeds. After enabling, the torpedo searches for a target by active acoustic means while maneuvering in a helical path. Echoes from the target cause the torpedo to steer toward the target until contact is made. If the torpedo loses the target, it searches for a short time in the general direction in which it is traveling and, if unsuccessful in relocating the target, resumes a helical search.

The acoustic homing system of the torpedo also has a passive feature that allows the torpedo to respond to an acoustic noise source whose frequency level is within the sensitivity range of the receiver. During the torpedos normal search pattern, passive homing on a target noise source aids in target acquisition, increasing the attack capabilities of the weapon. The passive homing feature is eliminated by a coiling device when the torpedo rises above a certain depth to prevent attack on the launching ship.

11C6. DASH

The drone antisubmarine helicopter (Dash) combines the elements of surprise and mobility

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offered by aircraft with the superior detection and fire control equipments of the surface ship.

This system places a ship-controlled drone helicopter, armed with an A/S weapon (fig. 11C9) over the submarine's position. The weapon can be either a nuclear or conventional A/S weapon.

The components of the Dash system are the helicopter itself, the radio control units, and the ordnance payload. The helicopter is housed in a small hangar on the weather deck of the ship. Dash is a feature of new A/S ships, but the majority of Dash installations are on the World War II destroyers updated by the FRAM (Fleet Rehabilitation and Modernization) program.

11C7. ASROC

The Asroc missile is a supersonic, shipboard-launched (fig. 11C10), solid-fuel, rocket-propelled antisubmarine ballistic projectile. The missile has two configurations—one with a depth charge and one with a torpedo.

The goal achieved by Asroc is the destruction of submarines at long ranges. This objective is achieved by delivery of a torpedo or atomic depth charge through the air to a point in the water from which it can either attack under the most favorable circumstances or have the submarine within its lethal radius (fig. 11C11). The payload is a part of an unguided missile which is propelled by a rocket motor and stabilized by an airframe throughout its powered flight. Separation timers jettison the airframe and motor after a preset time. From separation to water entry, different methods of stabilization are employed, depending on the payload. The depth charge descent is stabilized by a fin network during the entire drop. The torpedo also has such a network, but it employs, in addition, parachute stabilization. Aside from

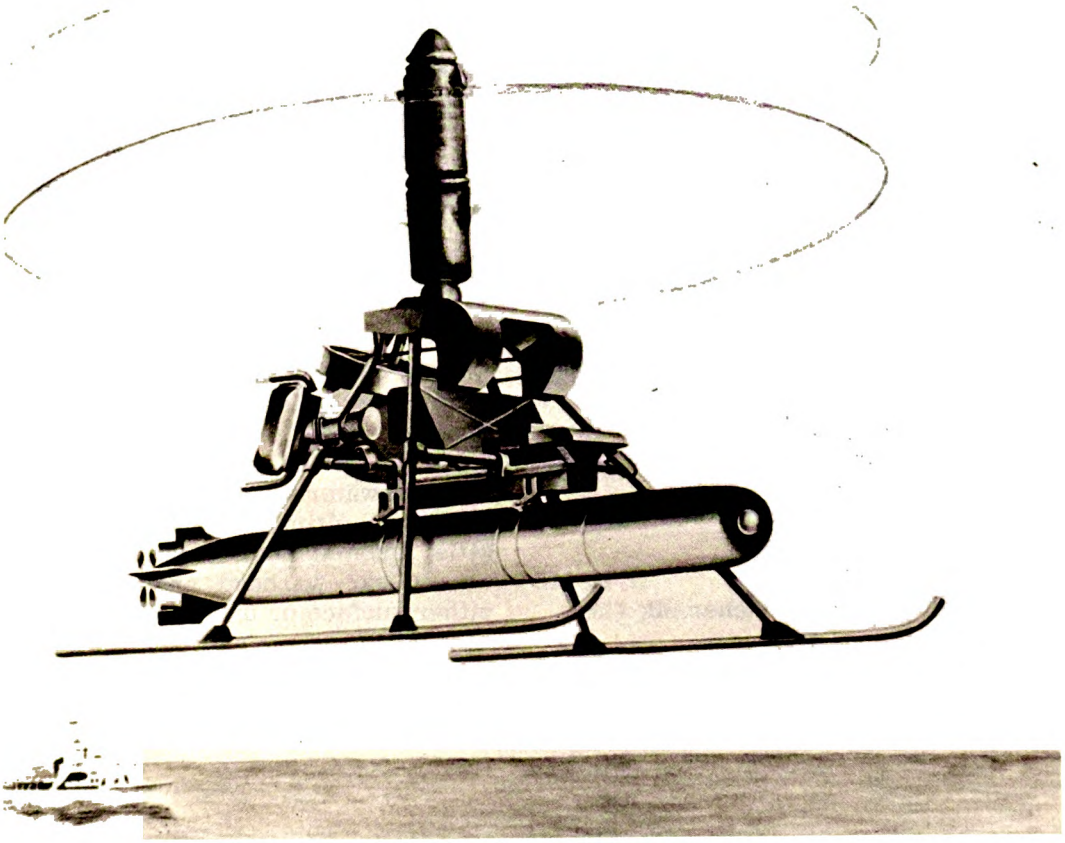

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Figure 11C9.—Drone helicopter armed with an A/S weapon.

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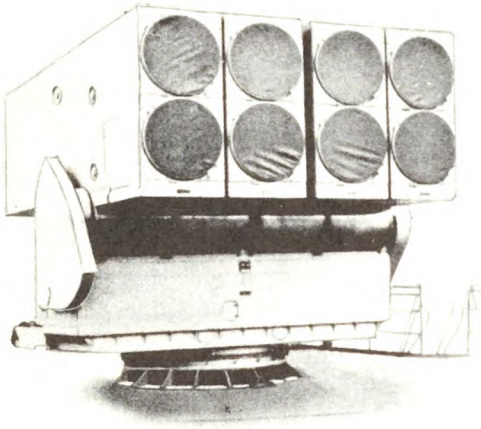

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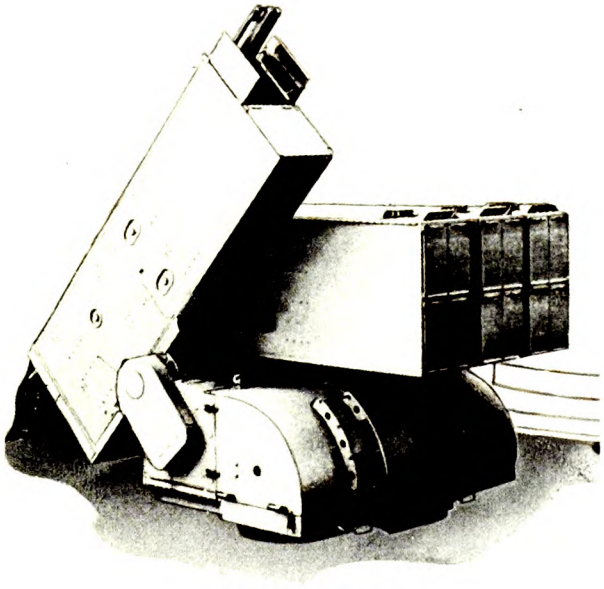

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Figure 11C10.—Asroc Launcher Mk 112.

stabilizing the torpedo descent, the parachute also decelerates it to a safe water entry velocity to avoid damaging the highly sensitive electronic components.

Before the missile is launched, the submarine is located by sonar, and the range, bearing, and other pertinent data are transmitted to the fire control system. The fire control system automatically computes the anticipated target position, sets a time-to-separate into the timers on the air-frame, and keeps the launcher trained on the desired water entry point, so that the missile can be fired at will by simply closing the firing circuit.

11C8. SUBROC

The Navy will get a potent addition to its growing arsenal of A/S weapons when SUBROC, (fig. 11C12), becomes operational in the fleet in the reasonably near future. This highly flexible, long range, tactical weapon will give a much longer reach and more powerful wallop to our defense against high speed nuclear-powered submarines than is offered by Asroc.

Subroc is a submarine-launched anti-submarine missile capable of delivering a nuclear payload with pinpoint accuracy against a submerged enemy miles away.

11C9. ASTOR

The new Mk 45 Astor (Anti-Submarine Torpedo) wire-guided, electrically powered, high speed torpedo is now in production and is expected to be declared operational soon. Astor is an underwater-to-underwater or surface torpedo which will ultimatly be deployed aboard hunter-killer submarines. It can carry a conventional or nuclear warhead and will be used against either surface or underwater craft.

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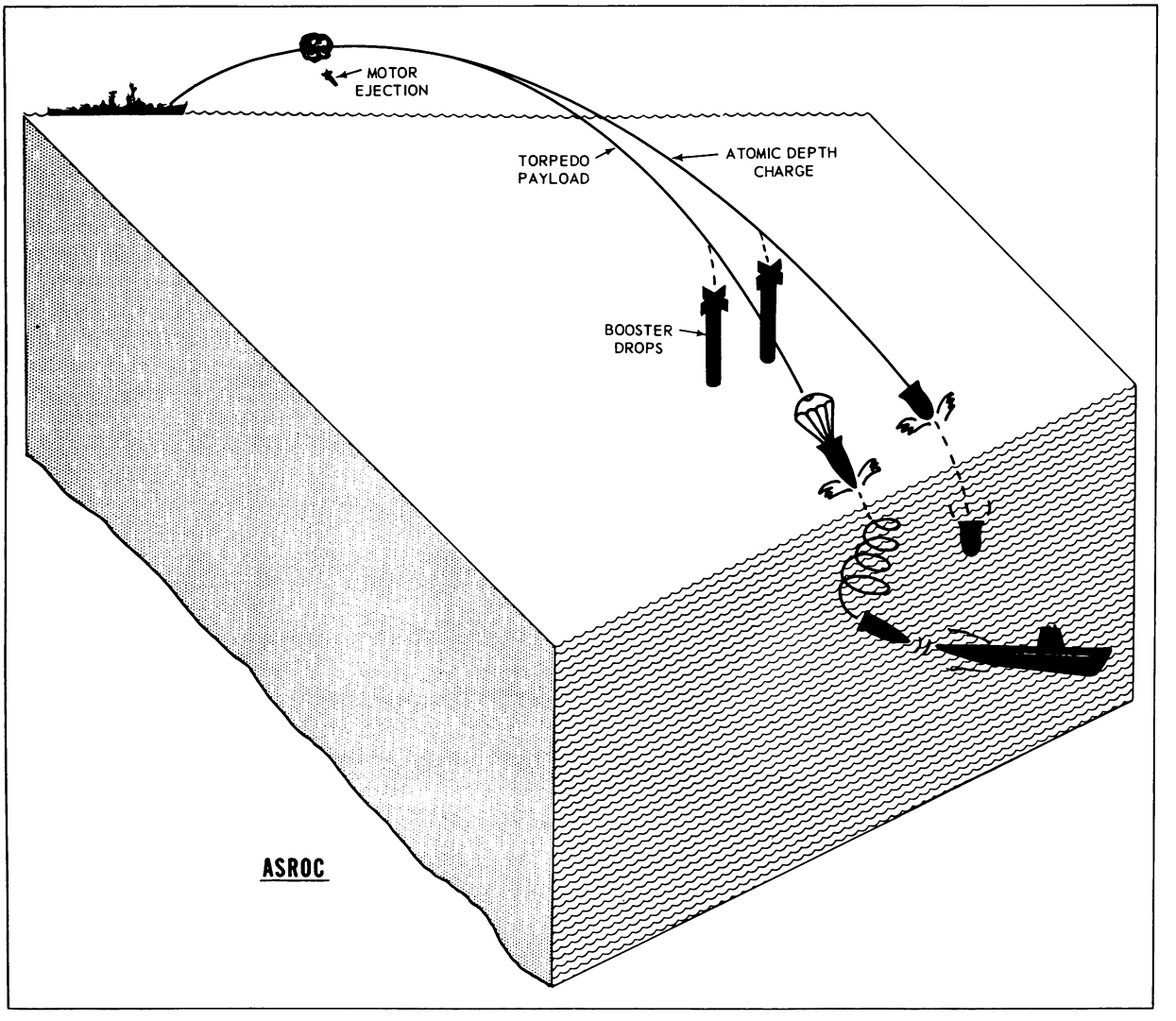

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Figure 11C11.—Asroc.

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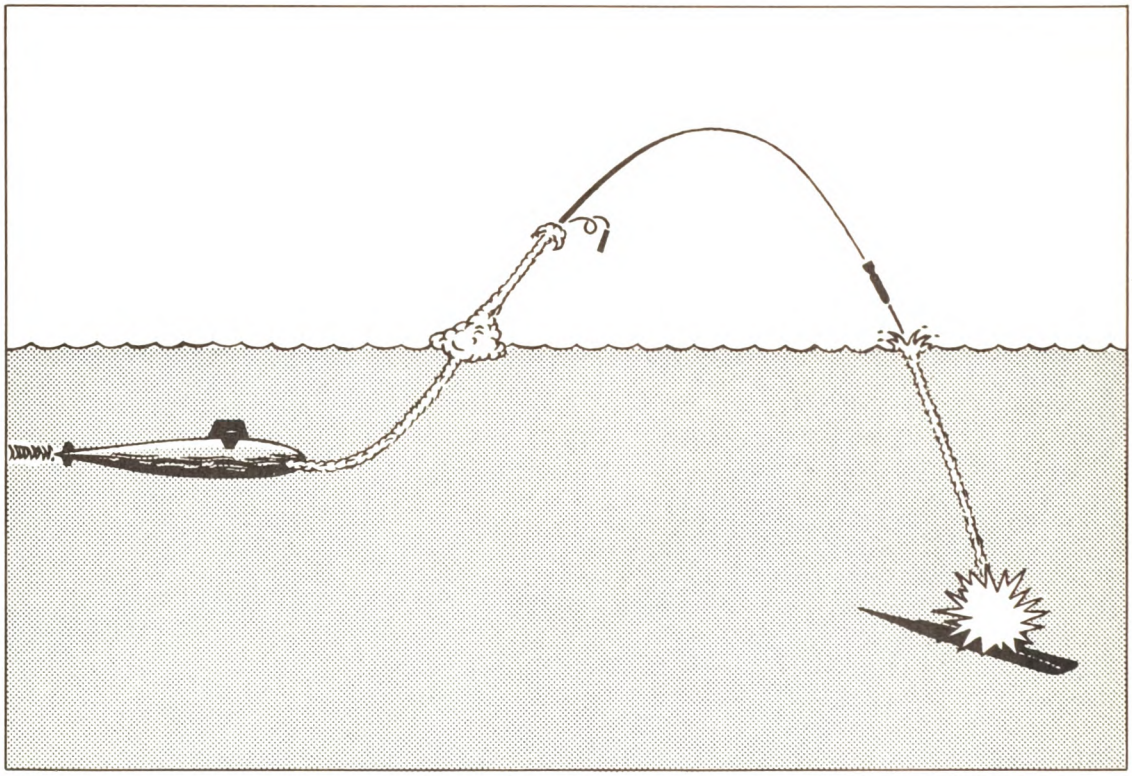

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Figure 11C12.—Artist's view of the trajectory of Subroc.

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D. A/S Fire Control and Attack Methods

11D1. A/S CONTROL STATIONS ON A DESTROYER

Since the destroyer is a primary type of A/S vehicle and is the type that many newly commissioned officers report to for first duty assignment, this article will concentrate on this type of ship in discussing ASW organization on shipboard.

The A/S mission of a destroyer type vessel is to detect, classify, attack, and destroy enemy submarines. The A/S control stations aboard (fig. 11D1) are:

1. Command control. Here the commanding officer keeps the battle control stations informed of the objectives and his seniors informed of the situation; orders the class of A/S attack and ordnance to be employed; makes final classification decisions; and in coordinated attacks, acts as safety observer.

2. Ship control. Here the officer of the deck conns the ship; assists in classification; operates tactical voice circuits; keeps all control stations informed of ship's maneuvers; relays command control orders to all control stations (ASW), weapons, CIC, engineering and damage control), type of ordnance, and final classification.

3. Information control is CIC where all CI radio-telephone nets are operated; tactical information is disseminated; air, surface, and subsurface contact information is plotted, displayed, evaluated, and disseminated; and search arcs and search plans are recommended.

The evaluator assumes advisory control in CIC during an A/S search. Course and speed recommendations, etc., are passed continually to the conning officer on the bridge.

4. Antisubmarine control is responsible for underwater detection, localization, classification, conduct of deliberate attacks, control of noisemakers, solution of the underwater fire control problem and destruction of the enemy submarine.

Sonar control and underwater battery plot are controlled by the A/S officer during an A/S attack. Advisory control is usually passed from CIC to UB plot for the actual attack.

Of all types of battle actions A/S requires the most in coordination and cooperation. From the time of the initial contact report right through classification, amplifying reports, control orders, weapon status reports and orders, firing orders, and regain contact procedures, the UB plot personnel are working directly with combat

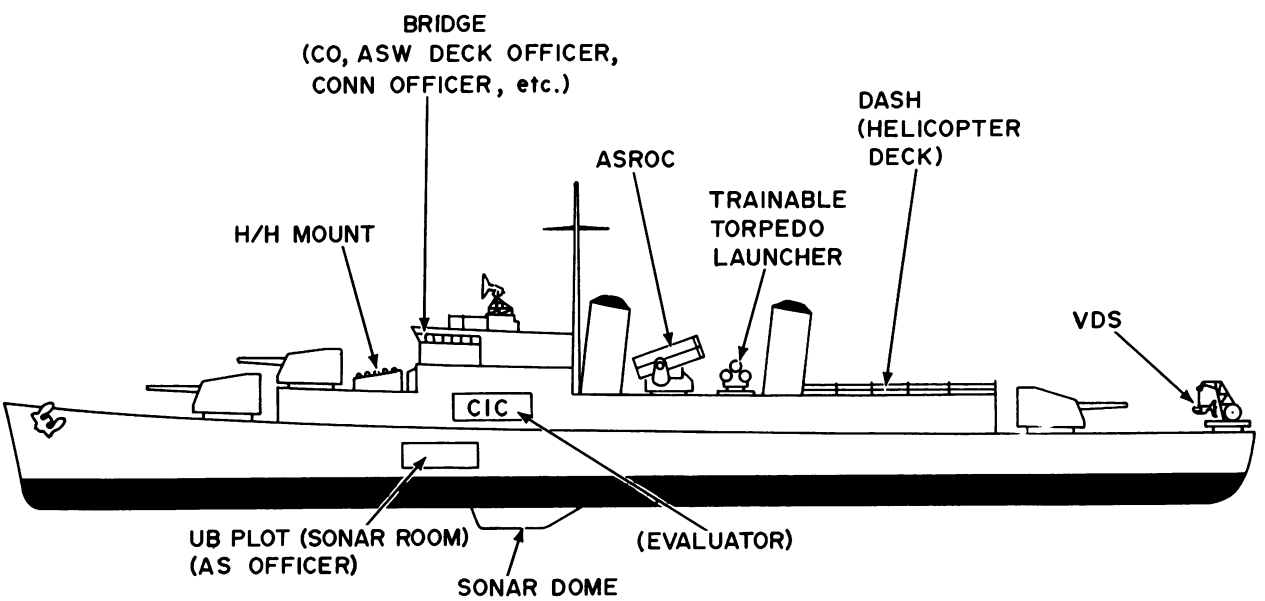

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Figure 11D1.—A/S control stations. (DD-692 FRAM destroyer).

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information personnel in an exchange of information and instructions. Without going into details at this time, but to give some conception of the speed of action required, the pass interval (i.e., time from original contact to time of firing the A/S weapons) for a single ship using an SQS-4 sonar with Mk 5 attack director, using speeds of 20-25 knots, is about three minutes. This time varies tremendously however, and could be as high as 15 or 20 minutes or as low as a few seconds!

11D2. MK 105 FIRE CONTROL SYSTEM AND HOW IT IS USED

Figure 11D2 schematically shows a basic underwater fire control system (UFCS) and the weapons it is possible to control. As a junior weapons officer you could be assigned as Fox division officer. In that billet you would normally also be the ASW officer and operator of the attack director, so it is imperative to understand the elements of the system and how they work together.

MAKEUP OF THE BASIC FC SYSTEM. The basic system consists of an attack director, sonar equipment, and stabilization computer. To complete the system the weapons to the right in figure 11D2 must be added. No one destroyer has all of these weapons installed, and the attack director, which is an electromechanical analog computer, cannout compute for all the weapons simultaneously. Different modifications of the systems are designed to handle any two or three of the weapons at the same time. Other combinations require modification of the attack director. But for purposes of explanation, assume that the attack director handles all weapons.

Other systems can handle additional weapons such as Asroc.

The attack director is an electomechanical analog computer using component solvers and related mechanical computing units and accepting synchro-transmitted and cranked-in inputs. The stabilization computer is also an electromechanical analog computer. The ballistic computer is more electrical than mechanical in that it uses resolvers rather than mechanical component solvers. The angle solver is electromechanical, like the attack director.

DATA FLOW. Consider the basic system first (those units on the left in fig. 11D2). The attack director receives the following synchro-transmitted inputs:

1. Own-ship course (Co) from the ship's gyro-compass.
2. Own-ship speed (So) from the ship's rodmeter or pitometer log.
3. Target range (Rq), relative bearing (Brq), and depth (Hq) from the sonar system.

The attack director may receive the following cranked-in inputs:

1. Target course (Ct) and target speed (St).
2. Parallax base (p).
3. Effective range (Re).
4. Time of flight (Tf) and dead time (Tq).
5. Depth charge or hedgehog projector charge sinking rate (Sd). The inputs actually entered depend on what weapon is being used.

The attack director solves the problem and transmits the following outputs to the weapons (depending on what the inputs are and what weapons will be controlled):

1. Time to fire (Tud). This is a firing signal.
2. Course to steer for the attack. (More precisely, the director puts out a correction, jCo, to present own-ship course). This is transmitted by synchro to the ship's bridge to be followed by the helmsman.
3. Stabilized weapon train angle (B'gr).

The right-hand side of figure 11D2 shows which of these outputs each type of weapon uses.

To the sonar system the attack director transmits increments of generated sonar range and bearing (ΔcRq and ΔcBrq), for position keeping and aided tracking when the target contact is momentarily lost.

The sonar equipment feeds Rq, Brq, and Hq to the attack director, and receives from it the generated increments mentioned above. It also feeds Brq and target depression angle (Eq) to the stabilization computer, which latter in turn feeds stabilization signals back to the sonar system.

The stabilization computer is an electromechanical computer which receives roll (M) and pitch (N) signals either from a special pickoff in the ship's gyrocompass or from a separate stable element in underwater battery (UB) plot. (Different installations differ in this.) It puts out stabilization signals to the weapons and to the sonar system.

DATA RECEIVED BY WEAPONS. The depth charge racks receive only a Tud signal for release of depth charges at the proper instant.

The fixed H/H mount receives a Tud signal and a continuous transmission of M. A crewman at the mount, by matching pointers, continuously tilts the spigots so that they point dead ahead as the ship rolls.

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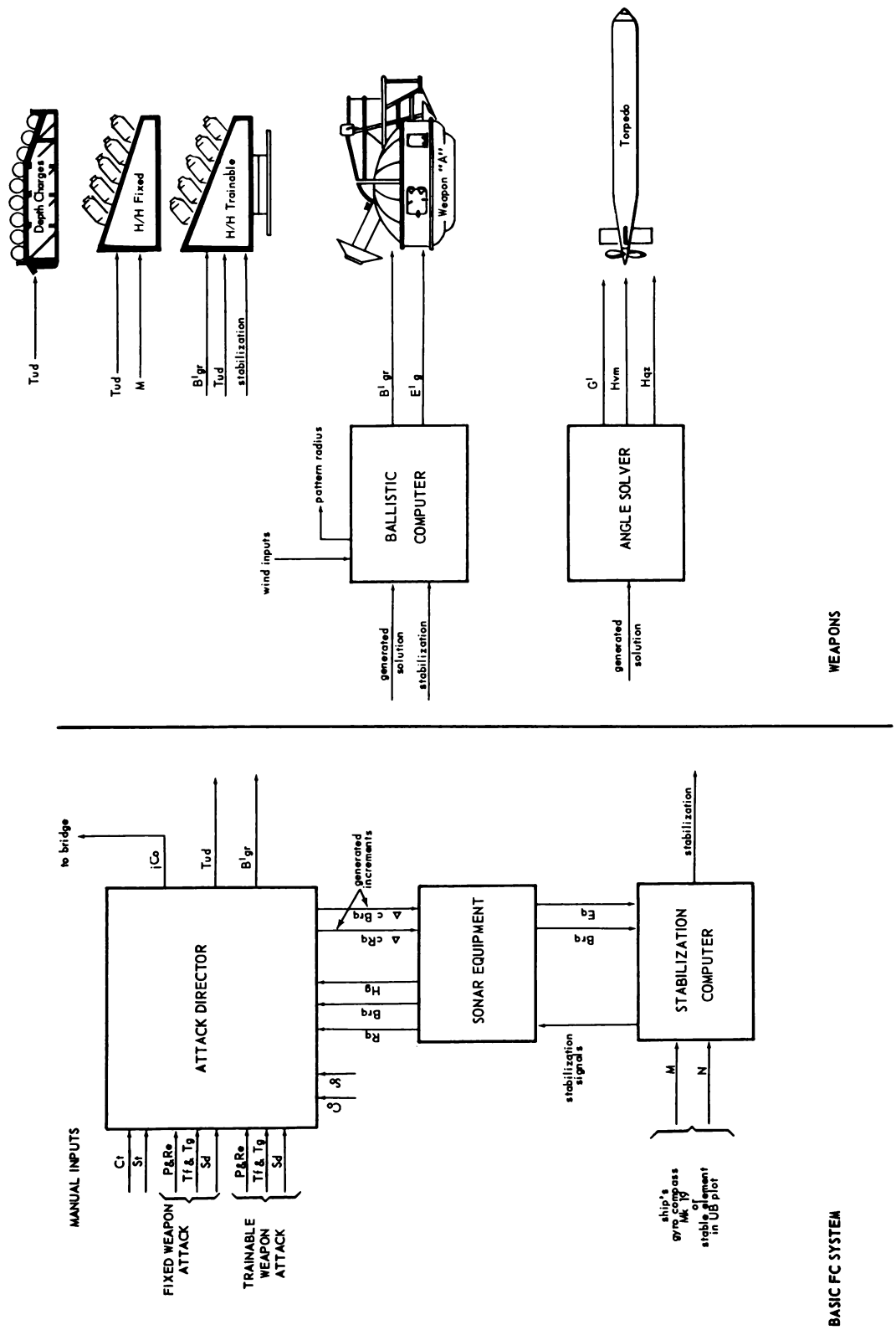

Figure 11D2.—Basic UFCS. Block Diagram.

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The trainable H/H mount receives B'gr, Tud, and stabilization signals to keep the weapon aimed at the point on the water below which the submarine is located.

The A/S rocket mount (weapon A) requires more than these data for firing. The attack director's generated solution and the stabilization computer's signals go first to a ballistic computer, which receives cranked-in wind inputs and pattern radius inputs. From these the ballistic computer develops B'gr and weapon elevation (E'q), which go to the rocket launcher. Tud is not necessary because the weapon (except while being loaded) remains continuously aimed to deliver the rockets to the target location, within an area determined by the radius pattern input.

The torpedo similarly requires a different solution, so that generated solution from the attack plotter goes to an angle solver which develops stabilized torpedo gyro angle (G'), run depth order (Hqz—the depth at which the torpedo runs and begins its search pattern), and run order (Hvm), which determines how far the torpedo runs before its homing equipment is activated (enabled) and it goes into its search pattern.

HOW THE UFCS FUNCTIONS IN AN A/S ATTACK. The A/S attack is one that takes a maximum amount of cooperation between the different stations. The A/S attack team includes underwater battery plot, the sonar control room, the conning station, CIC, and the weapon mounts. They are connected by the sound-powered battle telephones.

When a contact is made, it is plotted on the DRT board and evaluated by CIC which informs the captain on the bridge of the range, depth bearing, and speed of the contact. The captain decides whether to attack and which weapon to use. The sonar operator keeps the sonar on the contact at all times. The attack director operator sets up the director and sets the various inputs for the particular weapon designated. CIC maintains a track of the contact and supplies the director operator with the initial target course and speed.

The attack director operator and sonar operator work closely together until they achieve a solution and so inform the conn and CIC. Conn steers the ship along the course as directed by the attack director and gives the order to fire when Tud is zero.

Trainable weapon mounts are automatically driven in train and will follow the solution of the attack director. CIC maintains a plot of sub movement. (CIC can be of invaluable help to UB plot by keeping them informed of the direction of maneuver of the submarine.)

11D3. THE ATTACK

Antisubmarine warfare is currently in a state of revolution. Hedgehogs and depth charges will remain in fleet use for the immediate future. These weapons, however, are severly limited and, as previously mentioned, are on the way out. ASW in the future will be waged by ships using Asroc, Dash, etc., to kill submarines at greater distances.

There are two types of ASW attacks—urgent and deliberate—and the use of one or the other depends on the tactical situation. An urgent attack is a harassing attack on a submarine and is delivered in the minimum possible time. An urgent attack is made on a submarine which is in position to menace any ship in the body of a force or formation. The urgent attack normally consists of an attack that is destructive in nature and employs all weapons that will bear. Accuracy is usually sacrificed for speed.

Preparation for a deliberate attack begins even while the urgent attack is in progress. A deliberate attack is delivered when the tactical situation allows time to obtain accurate weapon data. The most effective antisubmarine weapon required by the tactical situation is used. The deliberate attack is therefore a concentrated attack to kill. Any consideration other than the killing of the submarine is ignored.

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E. Antisubmarine Units, Formations, and Operations

11E1. INTRODUCTION

A/S forces include surface craft, aircraft, submarines, and shore installations. In this section we shall study the A/S capabilities of such units, particularly surface craft, and then briefly investigate how they are used in formations designed for ASW. This discussion is intended only as an introduction, not as a substitute for NWP's and related publications which are the primary sources of tactical doctrine.

11E2. SURFACE CRAFT

Since the advent of modern submarines, the surface ship has been the primary vehicle of antisubmarine warfare. It is now meeting strong challenges from improved submarines and the most advanced A/S helicopters.

A primary advantage of the surface ship is its available manpower. It has more men on board than any other type of antisubmarine craft. This not only allows more efficient operation, but also enables the ship to perform other tasks and functions at the same time that it is engaged in antisubmarine operations.

The great stamina and endurance of the surface ship also gives it a marked advantage over aircraft and submarines. It is thus the most effective craft to implement today's "hold down" tactics.

In addition, the surface ship has a greater variety of detection equipment than any other antisubmarine craft: active and passive sonar, radar, ECM, sonobuoys (occasionally), and visual.

In weapons also the surface ship has a greater variety: depth charges, torpedoes, and either hedgehogs, weapon ALFA, or Asroc. Aside from the sheer variety of weapons, the surface ship also has the great advantage of having a much larger reload capacity. All other antisubmarine craft have a strict limit on the amount of ordnance they can carry.

A further capability of most surface ships is a highly accurate and stabilized fire control system. The accuracy of surface ship fire control equipment is equal to or greater than that of any other antisubmarine craft.

A prime advantage of the surface ship is its ability to conduct all weather operations. Impaired visibility, darkness, storms, or rough seas do not prevent the surface ship from performing its mission, detecting a submarine, or launching an attack.

The final advantage of the surface ship is its long sustained time on station. In this respect, and in some others such as all weather operations and accurate fire control systems, the submarine is challenging the surface ship for the role of the most effective antisubmarine vehicle.

These characteristics however, best adapt the destroyer type vessel to the following ASW functions:

1. To search for submarines (either on patrol, in hunter-killer operations, or while escorting), to establish their location, and to engage in direct attack upon them.
2. To coordinate A/S attacks with other surface vessels and with aircraft (rotary-wing, or fixed-wing).

The five broad types of A/S operations in which the destroyer-type vessel may engage are:

1. A/S strike operations.
2. Hunter-killer operatins.
3. Patrol of assigned areas while continuously searching for submarines.
4. Escort of merchant vessels or other naval vessels not adapted to A/S search and direct attack.
5. Mining.

The most potent A/S surface ship today is the destroyer. Other surface types related to the destroyer that are designed to have direct A/S capabilities are destroyer escorts, frigates, and the new development types such as DDGs. Larger ships like aircraft carriers and cruisers are not designed to mount A/S weapons. Some of the newly converted missile cruisers, however, now have Asroc.

The appearance of new equipment and weapons and the modification of their older counterparts have resulted in the demand for more modern versions of ASW units. These may be brand new units or highly modified ships or submarines of our ASW forces. Some examples of ASW units follow.

Many ships of the DD type have or are undergoing improvements through the fleet rehabilitation and modernization (FRAM) program. (Fig. 11E1 shows an old Sumner class DD which has recently gone through the FRAM program.) Included in the program are the latest in ASW equipment such as VDS, Asroc, and the Dash system.

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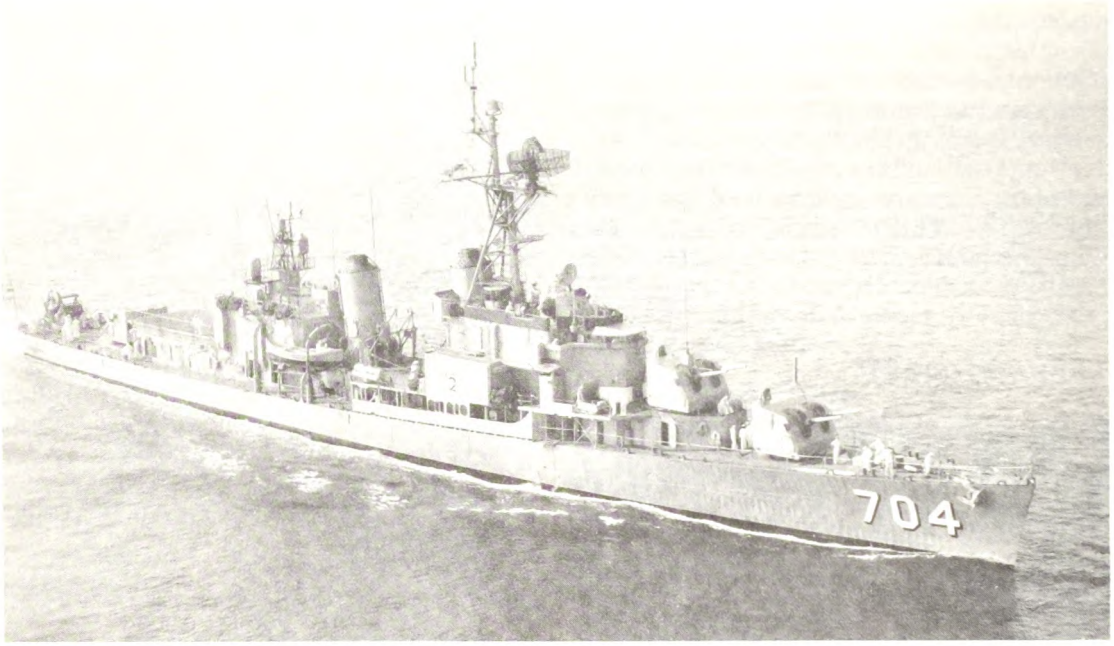

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Figure 11E1.—FRAM conversion, USS Borie (DD-704).

The new development types of destroyer such as the Sherman class (fig. 11E2), DDGs, and DLGs (fig. 11E3) also have the latest in ASW armament.

11E3. THE AIRCRAFT CARRIER IN ASW

Carrier task forces are the principal offensive formations of the Navy. The mobile airpower of carriers is used for employment against submarines and their bases, surface ships and their yards, aircraft and their airfields, and for support of amphibious, land, and air operations as well. Its importance in carrying out the mission of the Navy paradoxically makes the carrier an ASW liability because, basically, the carrier has no direct defense against submarine attack. We lost but one attack carrier to submarines in all of World War II. However, if we consider the advances made in submarine capabilities since then, its menace increases dramatically. To take the most devastating conceivable combination potentially available at the moment, we must protect against a fast advanced type of submarine armed with rocketborne target-seeking torpedoes, perhaps with atomic war head. To protect the fast carrier task force against this threat demands inclusion of CVS-type carriers (equipped with aircraft designed for A/S operations) a circular screen of destroyers, an outer screen of submarines, and inner screen of destroyer "pouncers," plus radar picket destroyers, and radar picket submarines. (Fig. 11E4 shows such a formation.) The A/S capability of a carrier is in the aircraft aboard, not in the ship itself. Some carriers have SQS-23.

The CVS-type carrier with hunter-killer team is the most effective offensive antisubmarine force yet devised. It will be described later in this chapter.

11E4. AIRCRAFT IN ASW

Aircraft, including such fixed-wing types as fighter planes, patrol bombers, and seaplanes, plus helicopters, have the ability to investigate distant contacts rapidly and are completely invulnerable to submerged submarines. However, unfavorable weather can ground aircraft, both carrier and shore based, and high seas can reduce radar and visual detection probabilities to the vanishing point.

FIXED-WING AIRCRAFT (fig. 11E5) have radar and ECM equipment which are effective

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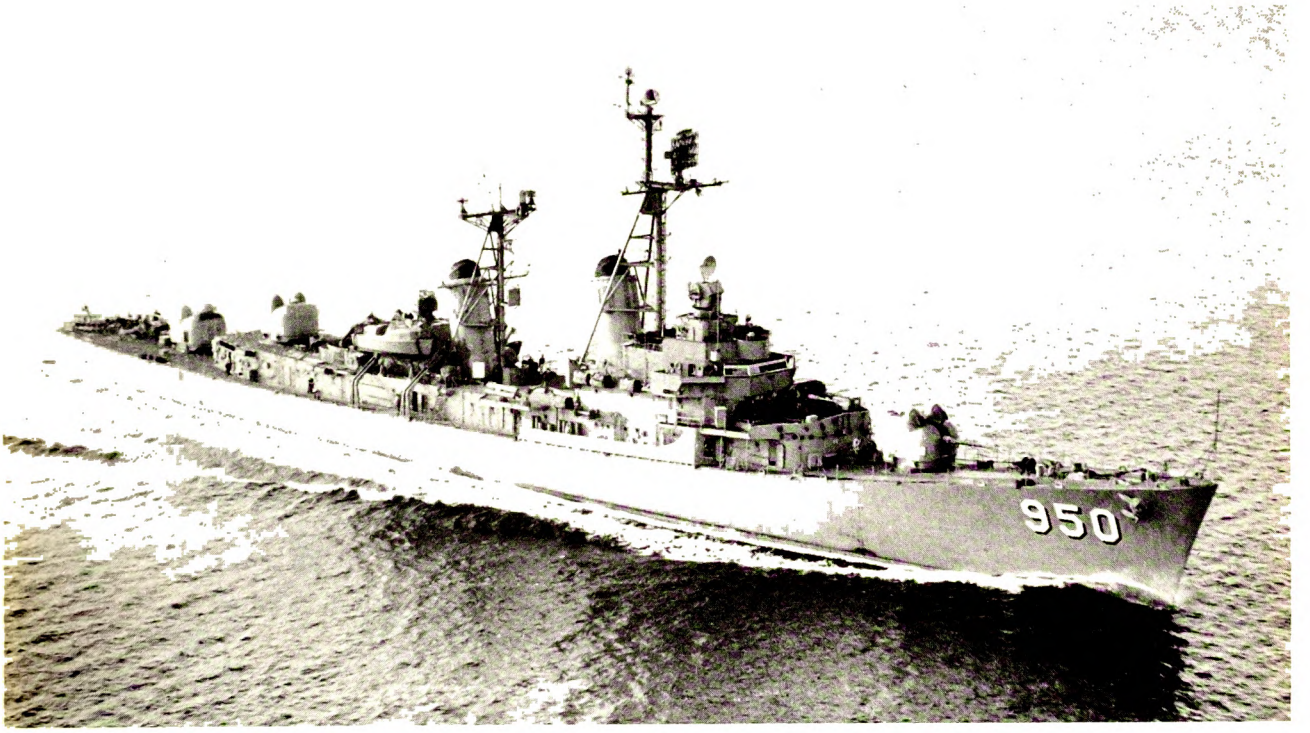

Figure 11E2.—USS Richard S. Edwards (DD950). 3.76

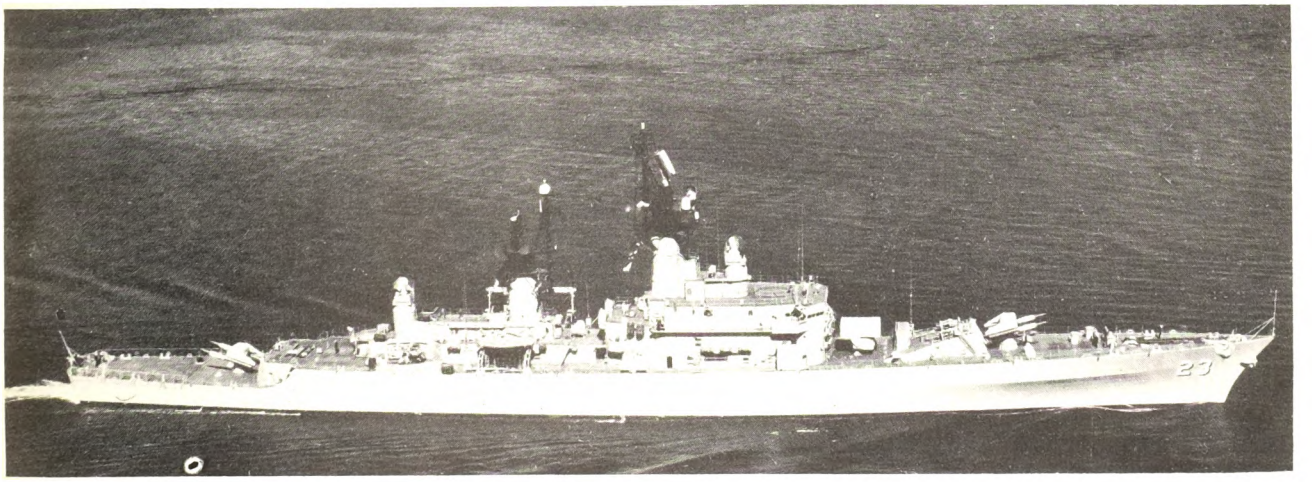

Figure 11E3.—USS Halsey (DLG-23). 3.76

if the submarine exposes all or part of itself above the surface. Against submerged submarines they can use radio sonobuoys. An experienced sonobuoy operator can distinguish one type of submarine from another and even recognize the type of propulsion plant. Under good sound conditions a sub proceeding at high speed on Diesels has been heard as far as ten miles. The use of sonobuoys is restricted, however, because only a limited number can

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Figure 11E4.—Typical task force steaming formation with two aircraft carriers, a cruiser, and circular destroyer screen.

be carried in the plane. Finally, fixed-wing aircraft have MAD (Magnetic Airborne Detection) equipment, but MAD is only effective when the submarine's position is fairly accurately known.

Fixed-wing aircraft can attack submarines with depth bombs (similar in principle to depth charges launched from surface vessels, except that they are fuzed to explode either hydrostatically on reaching a certain depth, or on contact with a solid target). Present doctrine includes as a normal method the use of homing torpedoes by aircraft against submarines.

Helicopters. The antisubmarine helicopter is an efficient search unit and is capable of attack as well as detecting and locating. It carries sonar gear and homing torpedoes. The A/S helicopter mission is to:

1. Detect, track, and destory submarines, singly or in conjunction with other aircraft or surface forces.
2. Provide A/S search and screening service for task convoy escort, and harbor defense forces.
3. Operate with A/S HUK (hunter-killer) forces.

11E5. SUBMARINES IN ASW

The submarine is itself an effective antisubmarine vehicle. It operates in the same medium

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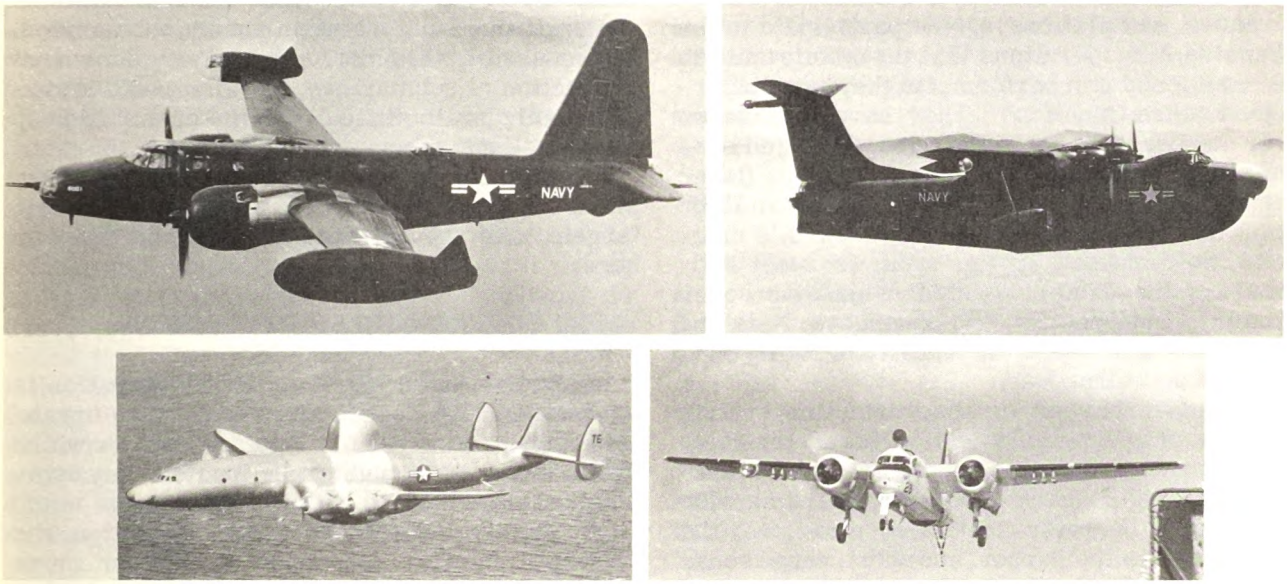

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Figure 11E5.—Fixed-wing type aircraft in ASW.

with and shares the target's advantages of concealment and passive detection. It can, like the target, take advantage also of the sound refracting properties of sea water, and it can track the target with less distraction caused by this phenomenon. Like the target submarine, it can go deep enough to escape the effects of surface waves and winds. It can hover silent and motionless for long-range passive listening.

The submarine can be employed in protecting the capital ships of a fast carrier task force, in detecting enemy submarines while working with a hunter-killer group, and in supplementing and protecting radar picket destroyers. Submarines can precede a fast carrier strike force into enemy waters to function as antisubmarine screens and as minelayers. Immediately before a strike, guided missile subs could be sent in to destroy enemy submarine installations (as well as other strategic targets) before enemy subs have a chance to put to sea.

Like any other vehicle, the A/S submarine has limitations. To find the enemy the submarine must be deep, but to communicate this information to the surface forces it must be shallow. To maintain the silence essential for most effective listening, it must not move. But to get information to someone who can do something about it, the A/S sub must break off the contact or expose its location by surfacing to communicate. And of course, an A/S submarine is always faced with the nerve-racking possibility of being mistaken for the enemy by its own force. These disadvantages will in some degree be overcome by developing new communication methods which will enable the submarine to remain in positive, rapid, and reliable voice communication with the remainder of the force while remaining submerged. Successful multiship coordinated operations depend on reliable communications and the submarine cannot participate until adequate communications have been developed and made available to the forces afloat.

The most effective antisubmarine submarine is the nuclear. These ships have as their strong points the counterparts of the two major weaknesses of conventional submarines. Nuclear ships are fast, whereas conventional submarines must operate at very slow speeds unless they are to be forced to surface or snorkel in a short time.

Furthermore, nuclear submarines can go out and remain submerged on station for extended periods, whereas conventional submarines must have recourse to the surface frequently for battery recharging. Conventional submarines must also withdraw to friendly waters to refuel, unless they desire to take the risk of surfacing in enemy waters to refuel.

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11E6. A/S SHORE INSTALLATIONS

Shore installations cannot participate in the offensive A/S operations that the mobile units so far mentioned can perform, but they have important defense functions. They have cognizance over harbor defense submarine-detection systems using radar, sonar, magnetic loops (large rectangles of cable laid across the ocean floor which detect any distortion of the earth's magnetic field caused by an iron or steel body crossing the cable), heralds (a passive sonar system), hydrophones, and sonobuoys. Nets and mine fields are used in actually blocking submarines and torpedoes.

An ideal harbor defense detection system consists of magnetic detection loops (or early warning hydrophones) to seaward, hydrophones or sonobuoys to back up the loops, and heralds (long-range operator-controlled sonar near the approaches to the harbor, and short-range sonar units guarding the inner harbor). Surface and air patrols are responsible for the ocean areas to the approaches of the harbor.

11E7. A/S OPERATIONS

Since we are primarily interested in ASW as it relates to destroyer type surface vessels, let us consider briefly those types of A/S operation in which such vessels participate. These are the A/S strike, hunter-killer operations, A/S partrol and search and protective escort or screening. (Destroyer vessels also perform A/S mining, but this operation does not involve A/S detection equipment or weapons and is not taken up in this course.) The limited general discussion to which this text is confined is not to be considered a substitute for study of doctrinal publications such as NWPs, NWIPs, and related instructions issued by such authorities as CruDesLant.

11E8. A/S STRIKES

The A/S strike can be considered the prophylaxis of the submarine problem. Just as it is more effective to destroy the breeding places of disease-bearing mosquitoes than it is to swat at them even with very efficient swatters, it is more effective to destroy or reduce the enemy's ability to fabricate submarines than to attempt to destroy those already at sea. Even the most efficient ASW campaigns of the past did no more than keep the enemy submarine population in check.

A/S strike operations are offensive operations directed against bases and installations which produce and maintain enemy submarines. If successful, they not only reduce or prevent production of submarines, but also make it progressively more difficult for the enemy to keep in service the submarines he has.

A/S strikes differ substantially from other attack operations only in the nature of their targets, and they will therefore not be taken up here.

11E9. HUNTER-KILLER OPERATIONS

A hunter-killer (H/K or HUK) operation is a sustained A/S search and attack by an organized group of naval units in an area in which submarines are thought to be located. Any combination of A/S ships and aircraft may be used.

In the typical hunter-killer operation the CVS-type carrier, screened by five or more destroyers, will employ embarked fixed-wing A/S search aircraft and helicopters in an offensive search patrol. When either the aircraft or the surface screen contacts a submarine, the detecting unit will become the contact area commander (CAC), and a search attack unit (SAU) of at least two destroyers will be detached to assist in the development of the contact. In the meantime, the aircraft will attempt to develop the contact in an effort to localize and destroy the submarines. If initial detection is accomplished by visual sighting, radar detection, or possibility by MAD or ECM (electronic countermeasures) gear, it will be localized by employment of electronic countermeasures such as sonar buoys. (See fig. 11B9). If the target position can be accurately located, the attack aircraft may attack with one of its weapons such as an atomic or conventional depth bomb, homing torpedoes, or rockets. Decision as to who takes command in the contact area is made on the spot and it can change from one unit to another as the situation develops. Generally, it rests in the unit with the best over-all picture of the situation or the strongest contact with the submarine.

Hunter-killer operations are divided into three phases:

1. The extended search by aircraft, resulting in a contact and attack on the submarine by aircraft.

2. The approach of the SAU to the submarine contact area (datum) to cooperate with the aircraft, if the aircraft attack has failed.

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5. The local search and attack by a search attack unit (SAU) in cooperation with the aircraft.

Once a contact has been definitely established as an enemy submarine it must be attacked until destroyed.

Figure 11E6 shows schematically the sequence of operations in one type of attack. In part 1, fixed-wing aircraft conduct a systematic search of the area, finally detecting a surfaced submarine by radar. Next, as the submarine's status and identity are investigated, it dives, and the aircraft drops a group of sonobuoys so that it can keep tracking the submerged target while it calls in surface units of the hunter-killer group and directs (vectors) them toward the sub. By this time it is necessary to re-establish the location of the submarine. The ships and aircraft do this in cooperation. The ships search by sonar; helicopters may use dunking sonar units; the other aircraft may drop more sonobuoys. When the target submarine is located, the ships attack, using depth charges, rockets, homing torpedoes, and such other weapons as are considered appropriate.

This attack pattern is more or less typical, and variations of it apply in the other operations described below.

11E10. A/S SEARCH

A/S search is the systematic observation by ships or aircraft of a particular area where submarines are thought to be located. Ships are more effective at detecting submerged submarines, but are much slower at it because of their relatively low speed (compared to aircraft) and limited radius of visual and radar coverage. Two or more ships usually work together in search because they can provide mutual support in an attack and because a submarine can evade

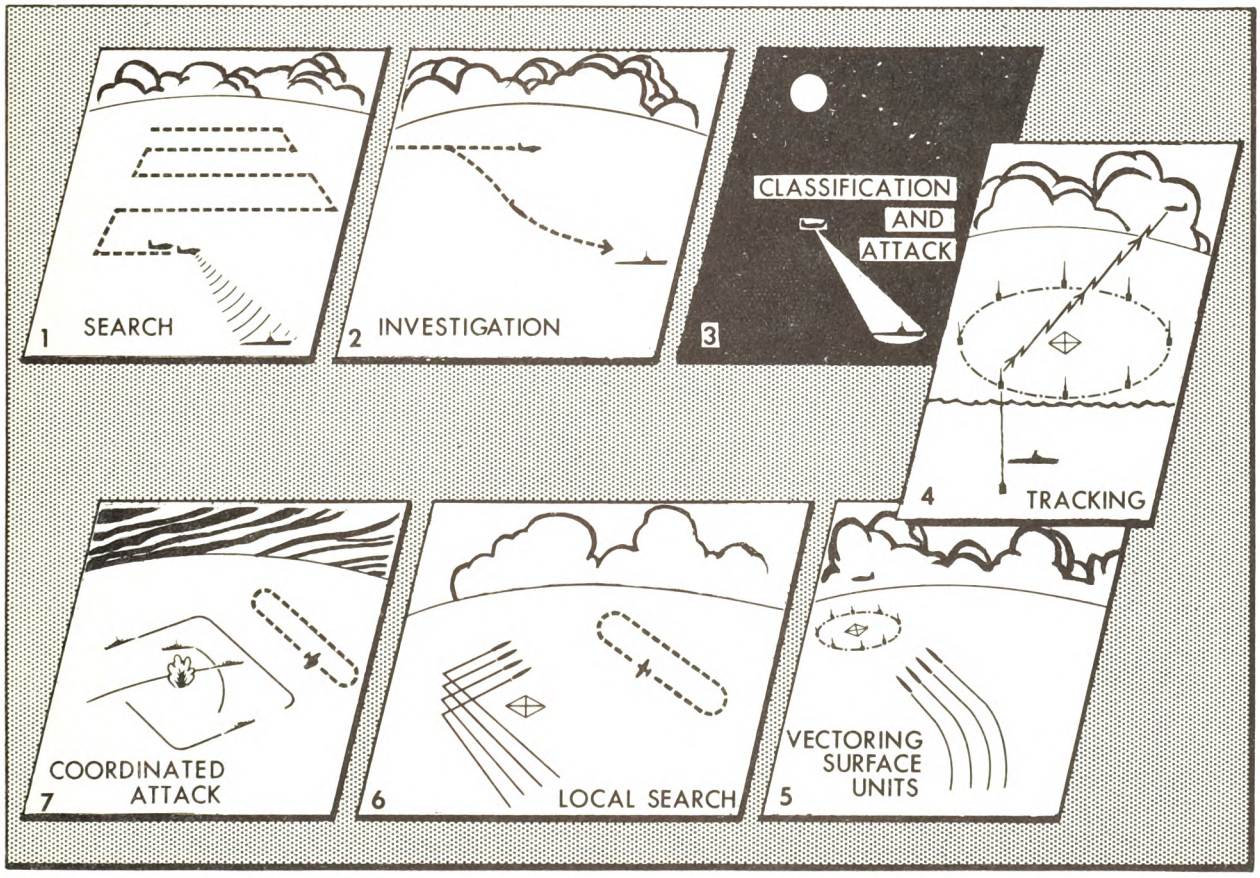

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Figure 11E6.—Hunter-killer operation. Schematic.

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two ships only with much more difficulty than it can evade one.

Fixed-wing aircraft can survey a wide area relatively quickly, and can efficiently detect surfaced and snorkeling subs, but their ability to locate submerged submarines is quite limited. Such devices as sonobuoys are effective at tracking submerged submarines only when they have been dropped fairly close to the submarine. However, search by fixed-wing aircraft has the additional advantage of forcing submarines to keep submerged; this can handicap a conventional submarine's operations.

Helicopters can use dunking sonar to search actively for submarines.

11E11. A/S PATROL

An A/S patrol operation is a systematic and continuous surveillance along a line, either stationary or moving, to detect submarines attempting to cross it. Patrol operations are actually closely related to search, and similar methods are used. Figure 11E7 illustrates the distinction between patrol and search.

11E12. ESCORT OR SCREENING OPERATION

To provide maximum protection against enemy aircraft and submarines, during wartime ships do not traverse the open sea singly, but in groups. A formation of naval vessels is called a force; a formation of merchantmen is a convoy. Around the group to be protected is a screen made up of destroyer-type vessels, and an area constantly being patrolled by aircraft. The screen is concentrated in the forward part of the formation. Figure 11E8 shows in simplified

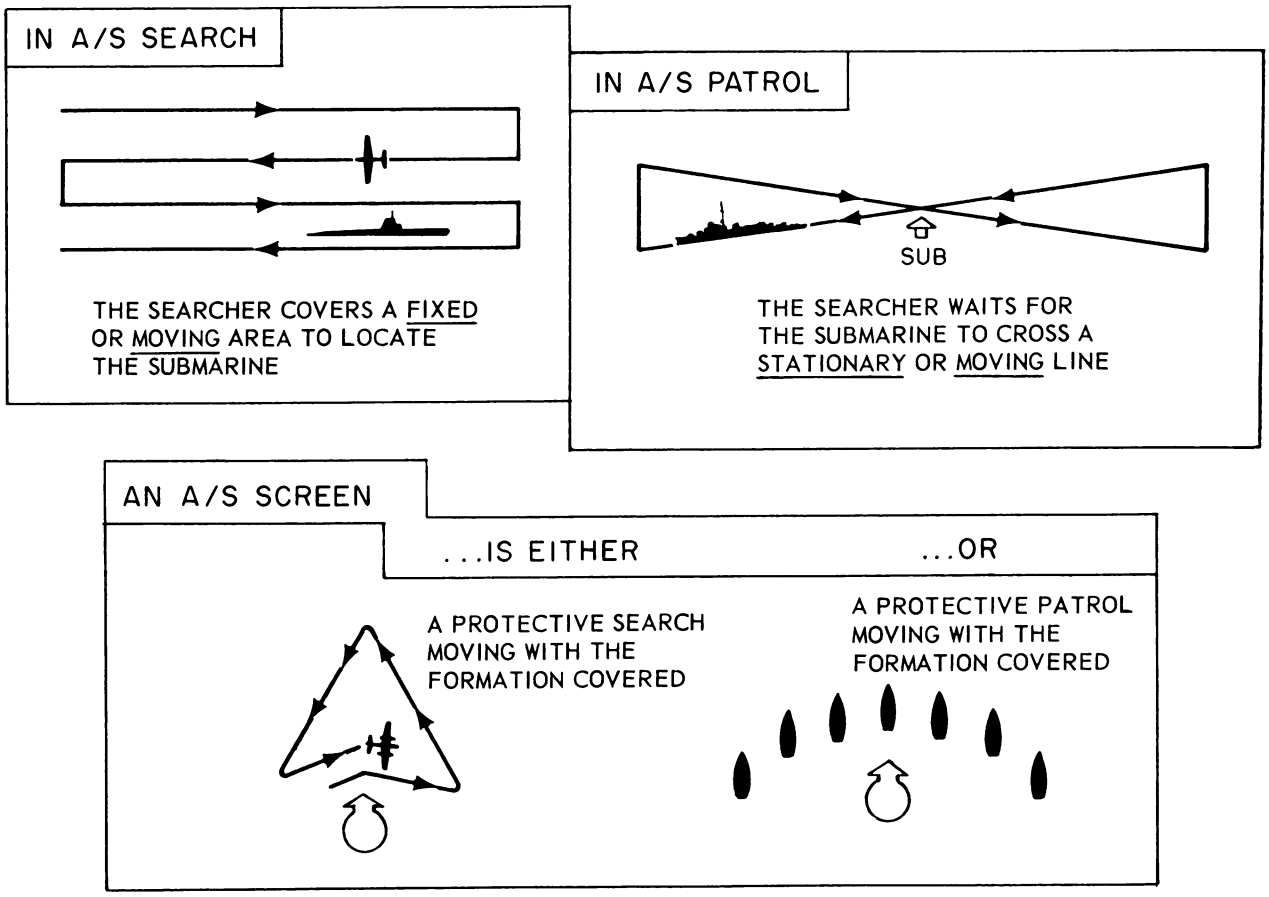

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Figure 11E7.—A/S search and patrol. Schematic

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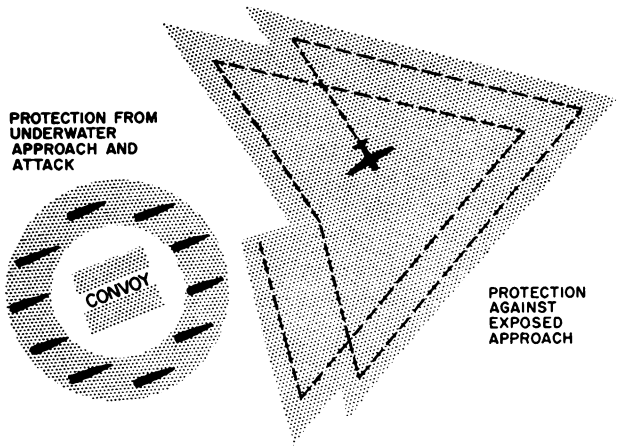

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Figure 11E8.—A/S escort operations. Schematic.

schematic form how a screen protects a convoy. Figure 11E4 is a photograph of a task force and screen.

11E13. DESIGNATION OF A/S FORCES

Forces to conduct A/S operations are designated in accordance with their mission. A force assigned to locate and destroy submarines at sea may be designated as a search, patrol, or hunter-killer force. A force assigned to close an enemy submarine base, or to close a strategic strait to enemy submarines, may be designated a mining force or a patrol force, according to the type of operation. A force assigned to protect shipping at sea against enemy submarines may be designated an A/S search, patrol, escort, or support force, depending on the type of operation. A screening unit can be part of a force, or it can be designated as an escort force. The list can be extended to include forces for the defense of harbors, fixed sea areas, or a coastal area.

11E14. EMPLOYMENT OF A/S FORCES

The employment of A/S forces for protection of a fast carrier task force has been mentioned previously. In addition an A/S force may be used in various numbers and combinations for antisubmarine operations. This text will take up singleship, multiship, and hunter/killer antisubmarine tactics.

11E15. SINGLE-SHIP A/S ATTACKS

In determining whether to make an urgent attack or a deliberate attack, the commanding officer or the OOD must consider the tactical situation and make a decision almost immediately upon sonar contact. The considerations and arrivals at this decision are stated in Allied Naval Maneuvering Instructions (ATP-1(A) and NWP 24. In general, the considerations depend upon the assigned task of the ship gaining contact and the degree of immediate threat to protected ships, own ship, or other ships in company.

Although an initial contact may be made while the ship is at general quarters, it is more probable that the normal cruising watch will be set.

In a normal cruising watch, sonar control is manned by an A/S watch officer (supervisor), search sonar operator, and standby operator. The Sonarmen assigned to a cruising watch must be capable of controlling any type of A/S attack on a submerged submarine, must be able to evaluate any evidence of submarine counterattack, and have sufficient tactical knowledge and ability to recommend course changes and maneuvers. Sonar is usually the only ASW station manned in a normal cruising watch. (This of course does not include the OOD or CDC officer.)

The members of the general quarters A/S attack team man their stations as soon as possible after initial contact is made. At the moment contact is made on an enemy submarine it is imperative that every effort be made immediately to gain the advantage and exploit it by attacking until the submarine is sunk. Attack on a submarine may be urgent or deliberate. If the contact is in a position to menace any ship in the main body of the force or formation, an urgent attack is immediately delivered. Deliberate attack follows when the formation is no longer in immediate danger.

Tests at sea have demonstrated that with favorable sonar conditions a single A/S ship, capable of 27 knots or more, and equipped with high-power low-frequency sonar, can hold contact on a freely evading high-speed, deep-diving submarine. Ship's A/S attack speed however, is commensurate with the ship's effective sonar speed (normal around 20 kts.) These tests have demonstrated that a single ship can attack and repeatedly reattack with weapon Alfa and similar standoff weapons with much greater maneuvering safety than she could if another ship were in close proximity. However, the principle of mutual

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support makes it desirable to have a second ship in the vicinity ready to be called in to take over the attack.

In conventional single-ship attack procedures, the ship must approach the submarine at high speed on a collision course, and conduct a devastating pattern attack. In some cases a one-two punch, successively using ahead-thrown weapons and depth charges, is employed. However, as recent experience indicates, it is often better to pursue the submarine, using ahead-thrown weapons, and upon losing contact because of short range, to open the range to enable sonar to regain contact, and then reattack.

When A/S attacks are to be by ahead-thrown weapons, rocket-assisted missiles, or atomic depth charge, the safety of friendly aircraft is a prime consideration. Low-flying aircraft such as MAD equipped planes or helicopters using dip sonar may be endangered when the A/S ship uses such weapons.

11E16. MULTIPLE-SHIP A/S ATTACKS

Initially, ASW was effected by single-ship attacks. The A/S attack was a battle of ship against boat and captain against captain. Experience taught that the exchange rate of surface ship for submarine was too costly. A more efficient and successful method of attack was required. Finally tacticians evolved the concept of the multiship attack. By constant training and experimentation, well-defined and effective multiship tactics have been developed.

A multiship A/S action is any A/S action involving two or more A/S ships maneuvering to a prescribed plan. The plan is designed to maintain the offensive by maximum rapidity of attack and continuous contact on the submarine. It is employed to maximum effectiveness in close-in attacks when two ships using ahead-thrown weapons work the submarine over until it is destroyed, contact is lost and cannot be regained, or the A/S action is terminated by higher authority. Successful two-ship coordination depends on rapid and reliable voice communications and complete exchange of information and intentions. Additional ships if available are employed as supporting ships by putting them on a circle around the contact or on a fence prepared to take over the attack or commence a search if contact is lost.

The new concept in ASW employs the long-range, standoff technique. This of course is due to the recent and continuing development of long-range A/S weapons, such as Asroc, Dash, and Subroc. The destruction of submarines at long range is desirable; however this ideal situation will not always be possible. Thus, single and multi-ship A/S attacks may still be used when the situation arises.

11E17. FUTURE OUTLOOK

No individual piece of equipment or type of weapon can solve the ASW problem. Now, and in the future, the task group commander must employ his various ASW units, either singly or in a combination, to attain their greatest advantage. Each type of ship, submarine and aircraft has its particular function; each has its definite limitations. For example, a destroyer has great underwater tracking and attack ability against enemy submarines, but is limited in speed; moreover, its performance is hampered considerably by rough seas. By the same token, the submarine is a superb sonar-detection vehicle, and can operate deep enough to escape adverse sea conditions that plague surface ships. Diesel submarine endurance capability, unsupported, approaches 60 days. This exceeds that of any conventionally propelled destroyer type. Nuclear types of course far exceed this figure.

Constantly weighing the array of weapons at his disposal, the task group commander selects the one (or the combination) that best accomplishes the task at hand.

Tactics will change with new developments of detecting equipment and weapons. Today, however, and in the near future, it still will require the combined efforts of all types of ASW units to beat the submarine problem.

Our ASW forces of 1970 and beyond will include many ships and weapons unfamiliar to us now. But the most advanced hardware, alone, will never assure victory. At the base of the tactical problem are the officers and men who will put this hardware to use.

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CHAPTER 12

ORGANIZATION AND COMMUNICATIONS

A. Battle Organization in U.S. Navy Ships: Principles and Description

12A1. SCOPE OF THIS CHAPTER

The tremendous military potential that any modern U.S. combat ship possesses is a function not only of the trained personnel and powerful armament aboard, but also of how they are organized to accomplish the mission the fleet has assigned to them. In preceding chapters you learned the fundamentals of the "conventional" weapons that make up the modern U.S. Navy's shipborne arsenal. This chapter presents the fundamentals of shipboard battle organization on combat ships, and briefly describes the communications system through which the ship's fighting potential is coordinated for its most effective employment.

12A2. FUNDAMENTALS OF SHIP'S ORGANIZATION

Any ship's organization is based fundamentally on instructions issued as NWPs by the Chief of Naval Operations, particularly NWP 50(A). Shipboard Procedures, and NWIP 50-1(A). Standard organization manuals issued by Atlantic and Pacific Fleet type commanders (e.g., Commander, Cruiser-Destroyer Force Atlantic) follow these CNO instructions as a guide, and individual ships set up their organization structures in accordance with these. An individual ship's organization is promulgated in its Organization and Regulations Manual and its Battle Organization Manual; other organization media such as charts and posted ship's bills are based ultimately on these sources. For details on shipboard organization not discussed in these pages, consult these sources.

A ship's organization may be based on its complement or its allowance. The complement includes the officers and men (by number, rank, and rate) assigned by the Chief of Naval Personnel to the ship in time of war. The allowance (a smaller number) itemizes the personnel assigned to the ship in peacetime. (The actual population of the ship is the on-board count or manning level; this may be yet another number, or may correspond to complement or allowance.)

In compliance with NWPs, a ship's organization normally is set up in five major parts—the battle bill, the administrative organization, the watch organization, the organizational bills (administrative, operational, and emergency), and the ship's regulations. We are here primarily concerned with the ship's organization as it functions in battle (or simulated battle) and related operations; from this point of view the most important parts of the organization are the battle bill and some parts of the organization bills.

A bill, by the way, is a written directive that prescribes a procedure for performing some operation, such as berthing the ship, or for dealing with some specific situation or emergency, such as fire, or for performing battle operations. A bill lists the things to be done, the material needed, and who is to take action. It identifies these last not by name but organizationally by billet or other organizational designation.

12A3. PURPOSES AND PROMULGATION OF BATTLE ORGANIZATION

The purpose of the battle organization on any ship is to:

(1) Organize the ship for battle and for wartime cruising by assignment of personnel to duty stations under the various prescribed degrees of readiness.

(2) Define communications between battle control stations within the ship, and provide information on interior communication systems.

Type commanders, under the direction of fleet commanders-in-chief, are not only responsible for furnishing to ships of the type an

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appropriate outline of battle organization, but also for coordination between commanders of the same type in different fleets. This assures a practical uniformity of battle organizations for all ships of a type. Thus interchange of personnel between ships or of ships between fleets does not present a major problem.

12A4. BATTLE CONTROL STATIONS

The key points of a ship's battle organization are the battle control stations. The commanding officer must rely on officers at battle control stations for the execution of his commands. Each station controls subordinate stations.

The eight primary battle control stations in combat ships of the Navy include (fig. 12A1):

1. Command control
2. Ship control
3. Operations control
4. Primary flight control
5. Weapons control
6. Engineering control
7. Damage control
8. Mine countermeasures control

Figure 12A1 shows communication lines between primary and secondary control stations. Since the diagram is a general one, it applies to specific types of ships only insofar as the type possesses the elements concerned. Primary flight control, for example, obviously doesn't apply to a destroyer. However, the organizational principle of using primary and secondary battle control stations as key points or nuclei about which the battle organization is constructed applies universally.

12A5. COMMAND CONTROL

Command control is exercised by the commanding officer at his battle station, which may be on the bridge or in commanding officer's tactical plot. From this station he directs the ship's course of action in battle by exercising control over all the primary battle control

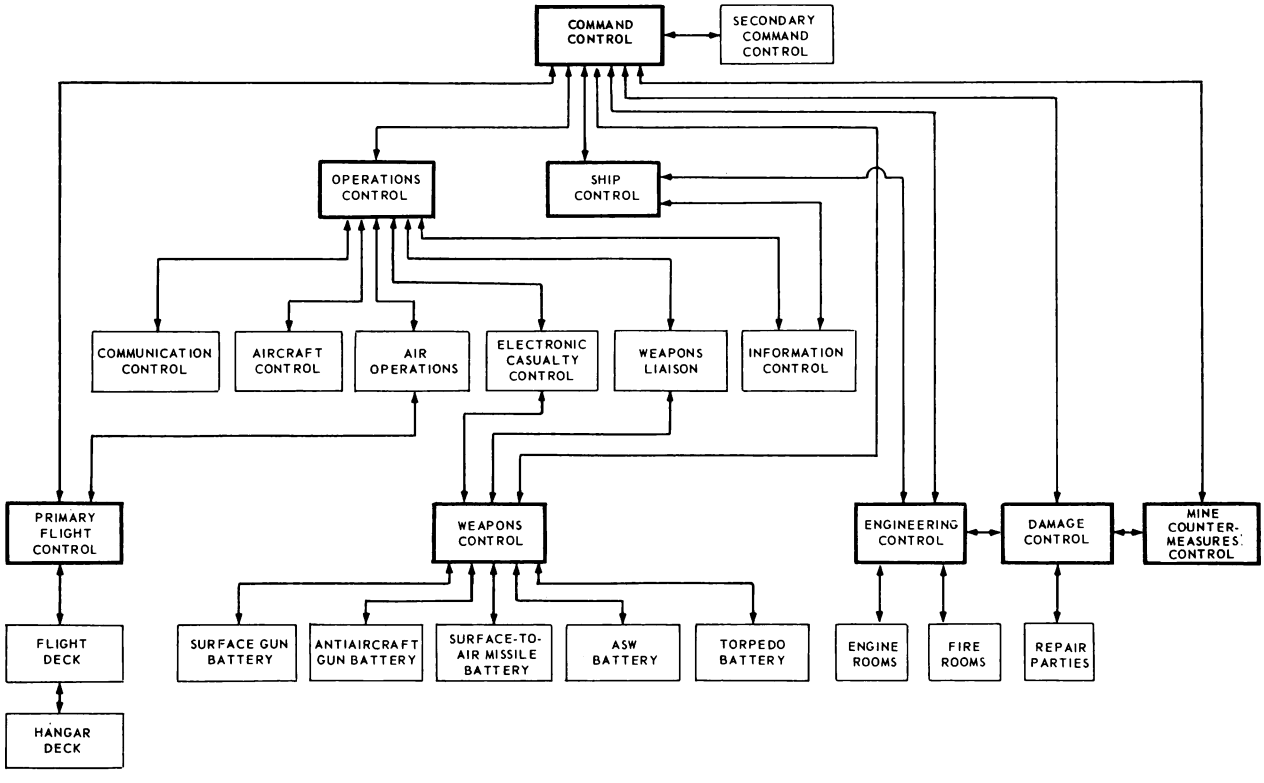

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Figure 12A1.—Battle control stations showing flow of communications.

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stations. Matters of paramount importance to the commanding officer during battle are the orders of his seniors in tactical command, conditions within the ship that affect his ability to carry out those orders, and information on external developments which have a bearing on the battle. His main responsibilities are to inform primary battle control officers of his objectives and to render decisions in matters having major influence on the combat effectiveness of the ship.

12A6. SHIP CONTROL

Ship control is under the immediate direction of the officer of the deck who is located on the bridge. The main functions of ship control are:

1. Conning the ship, as ordered by the commanding officer.
2. Maintaining operational control of tactical maneuvering communications.
3. Keeping other battle control stations informed of ship's maneuvers, present and anticipated.

Ship control receives direct assistance from CIC, commanding officer's tactical plot, a navigation detail, a signal detail, tactical voice radio operators, lookouts, steersmen, telephone talkers, and messengers. An efficient and dependable ship control aids command control by permitting the commanding officer to concentrate on the larger problems in fighting the ship.

12A7. OPERATIONS CONTROL

The primary objective of operations control is to assist command control in planning the correct course of action and to assist command and key battle control officers in executing that plan. Operations control is collectively applied to those activities under the cognizance of the ship's operations officer, which are:

1. Communications control
2. Aircraft control
3. Air operations
4. Electronic casualty control
5. Weapons liaison
6. Information control

operations control emanates from the ship's CIC which, on many ships, is the operations officer's battle station. The principal battle functions of operations control are to:

1. Keep command control informed of the tactical situation.
2. Assist ship control in carrying out its functions.
3. Perform operational evaluation.
4. Operate voice radio circuits.
5. Conduct radar search, identification, and tracking.
6. Analyze and/or conduct electronic countermeasures.
7. Plan operational schedules for aircraft (aboard aircraft carriers.)
8. Perform aircraft control duties.
9. Assist sonar search and tracking (ASW ships).
10. Perform combat intelligence duties.
11. Assist weapons control in target acquisition and designation.
12. Assist torpedo control in solving torpedo attack problems.
13. Obtain weather and aerological data.

12A8. PRIMARY FLIGHT CONTROL

Primary flight control consists of the control of shipboard aircraft handling and those operations incidental to launching and recovery of aircraft. During flight operations, the air officer is responsible for these operations, as well as the visual traffic control related to these functions. The air officer's battle station is primary fly. He receives his orders here directly from command control. During routine flight operations, the assistant air officer is also stationed at primary fly. Under battle conditions, though, he is at secondary fly.

12A9. WEAPONS CONTROL

Weapons control is under the direct and positive control of the weapons officer. The weapons control station (see fig. 12A2) provides centralized coordination and monitoring of missile systems and gun batteries. Located here is the equipment which furnishes displays and controls for selecting and tracking targets, for evaluating and processing data, for assigning targets to fire control systems, for loading the launcher, and for firing missiles at the optimum time.

Target indications are presented on the target selection and tracking consoles. The selected targets are tracked by operators and the target data sent automatically to a director assignment console. Here the relative threat of the targets is again evaluated, priority of engagement determined, and assignment of a missile or gun fire control director made. At the same time,

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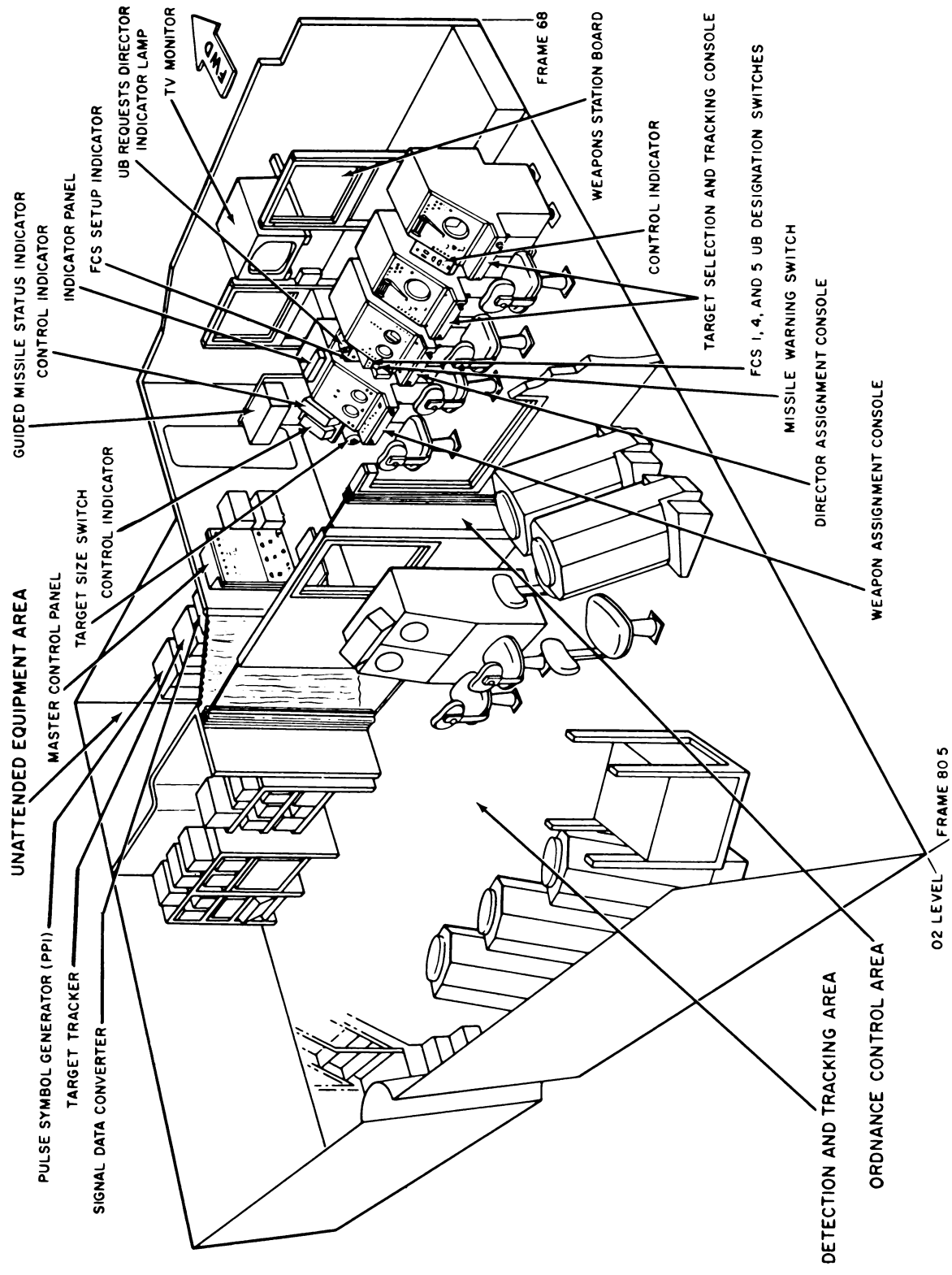

Figure 12A2.—Weapons control station.

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loading of the launcher is ordered for the top priority target from the weapon assignment console if director assignment has been made to a missile fire control system. Targets unsuitable for missile engagement are assigned to gunnery fire control equipment for separate processing.

12A10. ENGINEERING CONTROL

Engineering control is the engineer officer's battle station. Located at main engine control or a central control station, he supervises control of the main propulsion plant and auxiliary equipment.

The principal battle functions of engineering control are to:

1. Maintain and operate the engineering plant.
2. Exercise casualty control procedures.
3. Keep command control informed of the capabilities of the engineering plant and any major abnormalities.
4. Assist damage control in such functions as flood control, maintaining stability and trim, fire fighting, damage repair, and maintenance of watertight integrity.

12A11. DAMAGE CONTROL

The Damage Control Assistant (DCA) exercises control from his battle station in damage control central. On some ships damage control central is located in a central control station with engineering control. On other ships it is in a separate compartment of its own or at a designated repair party station.

The damage control battle organization is composed of damage control central; repair parties for hull, propulsion, weaponry, and air; and battle dressing stations. The weapons department, among others, is responsible for control of damage to its own equipment. There must be no doubt in the minds of the ship's personnel as to who is responsible for taking either normal or emergency action for damage control. Each officer and man must be familiar with the damage control organization of his ship and his own responsibilities to it.

There are two principal phases of damage control. They are the preventive phase and the action phase. The preventive phase begins with the preliminary design of a ship and continues through the construction, organization, maintenance, and operation of the ship. Efforts on the part of all departments in maintaining material readiness, training of personnel, and exercising readiness doctrine help place the ship in the most favorable condition to withstand damage. The action phase begins after the ship is damaged. This phase requires the damage control battle organization to take steps to promptly restore the offensive and defensive potential of the ship. The action taken is the cumulative result of the training and material preparations conducted during the preventive phase.

12A12. MINE COUNTERMEASURES CONTROL

Mine countermeasures control is a collective term applied to all minesweeping and minehunting functions which are within a ship's capability to perform.

Minesweeping procedures consist of sweeping an area of water for mines, either by covering it or traversing it with mechanical or explosive gear which physically removes or destroys the mines or by producing the influence fields necessary to actuate the mines. Direct control of minesweeping operations is exercised by the mine countermeasures officer whose battle station is on the bridge or in CIC except when actually using or recovering minesweeping gear, at which time he is on the fantail.

Minehunting includes all measures for detecting, accurately locating, identifying, and clearing mines individually. This clearance may be accomplished by explosive destruction, rendering mines safe and disposing of them, or by sweeping. Direct control of minehunting functions is exercised by the operations officer, whose battle station is in CIC. Mine disposal is the function of qualified Explosive Ordnance Disposal personnel and is under direct control of the officer in charge of the EOD team.

Channel conditioning, which includes all measures for the clearance of mines and minelike objects in areas and channels planned to be used in time of war, is a part of minehunting when not specifically assigned to an EOD team.

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B. Battle Organization in U.S. Navy Ships: Operational Aspects

12B1. BASIC WEAPONS DOCTRINE

During battle there seldom is time for lengthy consideration of the problems presented. To arrive promptly at a satisfactory solution, it is necessary that the more probable contingencies be anticipated and provided for. A basic weapons doctrine in writing, promulgated by the type commander helps to prepare the ship to:

1. Overcome surprise.
2. Develop maximum effective fire power in a minimum of time.
3. Make use of all automatic features of the equipment provided.
4. Simplify methods of control and provide each echelon with a clear-cut delineation of responsibility and authority.
5. Ensure automatic and instantaneous shift to secondary or auxiliary methods, with the replacement of personnel as necessary in the event of casualty or damage.

In concrete terms, weapons doctrine for his ship gives to a junior officer acting as director officer (or in some similar station) instantaneous guidance in answering and acting upon such urgent questions as the following—questions that demand quick action when you're faced with what may well be a genuine enemy target:

1. Must I get the captain's permission to open fire?
2. At what range may I open fire?
3. If there are several targets, how do I decide which to fire on first?

And there are many other questions that your ship's weapons doctrine is designed to guide you on when your ship is in action. Weapons doctrine specifies not only what you are to do in any of a number of given circumstances, but also indicates what you may expect of others, as well as what others expect of you. On any U.S. Navy ship you will find a special file or compilation of weapons doctrine, which you are expected to learn and follow without delay. Your ship's doctrine is in turn based on more general doctrine to be found in NWIP 50-1(A) and in directives issued by type commanders and other competent authorities.

12B2. THE SECTION AND THE BATTLE BILL

The primary organizational unit of the ship for administration, watch standing, and liberty is the section. Each division is broken down into three approximately equal sections, each completely adequate to maneuver and fight the ship within the limitations of the available personnel. Each ship assigns an adequate number of properly rated and qualified men (assignments are shown on the watch, quarter, and station bill) to man stations for any eventuality, including the stations for getting underway (Special Sea and Anchor Detail) and proceeding to sea for limited operations, as may be required by weather, surprise hostile activity, or other emergency situations.

Assignment of all personnel to individual battle stations is made in the battle bill, which is in chapter 3 of each ship's Battle Organization Manual. Officers are assigned by billet (job title). Enlisted personnel are assigned by billet number. A billet number is made up of a series of numerals, or a combination of letters and numerals, which indicate a man's division, his section, and (usually) his seniority or precedence in his section. As an example:

Billet No.	Description
1-204	1st division, 2nd section, 4th in seniority.

The battle bill lists the stations which must be manned under battle conditions and indicates the personnel requirements for manning those stations. The numbers, ranks, and rates of personnel assigned to battle stations by the battle bill should agree with the ship's wartime complement and peacetime allowance lists. The battle bill's summary is useful to division officers when making up the division watch, quarter, and station bill.

12B3. WATCH, QUARTER, AND STATION BILL

The watch, quarter, and station bill is the division officer's summary of the assignments of personnel to duties and stations specified in the battle bill and in each of the other ship's bills, which are contained in the ship's Organization Manual. One of the goals of the bill is to attain a smooth transition from one condition watch to another, thereby eliminating confusion and conflict of watches. Its primary purpose is to inform division personnel of their

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assignments. Technically, this is considered accomplished when it is posted on the bulkhead in the division. In practice, the division officer should disseminate this information to the men in his division, especially where there is a large proportion of new men.

The watch, quarter, and station bill shows for each billet the name and rate of the individual assigned, the station he is assigned for cleaning and maintenance, where he is quartered, his assignments in all condition watches (including Condition 1 or General Quarters—this is his battle assignment), and his assignments in specific operational and emergency bills. Figure 12B1 shows a common form of this bill in which the assignment information is entered on cardboard strips that slide into grooves in the billboard.

12B4. CONDITIONS OF READINESS

Conditions of readiness is a general descriptive phrase referring to a ship's ability to meet the preparedness requirements for combat. An Officer in Tactical Command (OTC) may order a condition of readiness for any of the following requirements: amphibious assault, antiaircraft, antiship, antisubmarine, damage control, engineering, or aircraft. Conditions of readiness do not describe any particular combat situations and do not establish a specific watch organization and operational arrangement. The phrase is frequently incorrectly used as if it were synonymous with either degree of readiness (see article 12B5) or condition watch (see article 12B6).

12B5. DEGREES OF READINESS

The objective of all watch organizations is security of the ship for all probable conditions. Secondary to this objective is the need for an optimum degree of efficiency in administration of the ship. To maintain such security, or readiness, and ensure the needed efficiency, requirements for specified degrees of readiness are set down. The amount of security furnished the ship is normally adjusted to the demands of the current situation by use of the six general degrees of readiness, which are as follows:

1. Complete readiness for immediate action.
2. Temporary relaxation from the first degree of readiness to enable personnel to rest and to permit designated personnel to draw and distribute action meals at their action stations.
3. A part of the armament ready for immediate action, the remainder on short notice.
4. A part of the armament ready for immediate action, the remainder at prolonged notice.
5. Peacetime cruising—no armament manned.
6. No armament manned, ship in port under peacetime conditions.

The general degrees of readiness, as described above, define the nature of the tactical situation in terms of the probability of attack and/or battle action and relate this situation to the combat capability of own forces required to meet the threat. General degrees of readiness apply to the WHOLE UNIT, whether an individual ship or a task force.

DIVISION					
NAME	RATE	BERTHING & LOCKER		CLEANING AND MAINTENANCE	BILLET NUMBER
		LIVING COMPARTMENT	BUNK & LOCKER NO.		
D. L. JOHNSON	BMC	A-308L	51-12	IN CHARGE	3-101
E. HAMILTON	BM2	C-205L	11-2	IN CHARGE MAIN DECK PORTSIDE	3-102
P. L. KELLY	SN	C-205L	7-3	AFTER CREWS HEAD	3-103

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Figure 12B1.—Part of a watch, quarter, and station bill.

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Particular degrees of readiness delineate the specific requirements for the battle organization components with an INDIVIDUAL UNIT. Condition watches (see article 12B6) are derived from the particular degrees of readiness.

A modification of a particular degree of readiness is assumed by the amphibious types for the conduct of amphibious operations. This is evidenced by their addition of a condition called 1A (one alpha). It represents an entirely different organization which is used to embark and debark amphibious troops and equipment.

12B6. CONDITION WATCHES

The condition watches established in the watch, quarter, and station bill are derived from the particular degrees of readiness promulgated in the Battle Organization Manual. Condition watches apply to specific shipboard watch organizations which satisfactorily meet the degrees of readiness perscribed in certain situations. They provide the optimum personnel/operational combination. The following tabulation shows the condition watches associated with each general degree of readiness.

General degree of readiness	Condition watch
First	I
Second	IE
Special	II
Third or fourth	III
Fifth	IV
Sixth	V

Battle readiness includes conditions I, IE, and II. Under condition watch I, for example, all ship's personnel man their individual battle stations. Condition I corresponds to General Quarters the full battle readiness condition. Under condition watch IE, the requirements are relaxed enough to permit the men to have their meals and brief relief periods at staggered intervals. Under condition II (which is called the special degree of readiness, and is used on large combat ships for such situations as extended periods of shore bombardment) the ship's armament is manned on a one-watch-in-two basis.

Condition watch III corresponds to a state of wartime cruising readiness. Ship's personnel man the wartime cruising watch stations, including part of the ship's armament, on a one-watch-in-three basis.

Condition IV is used for peacetime cruising. Condition V (relatively rare) corresponds to even more relaxed situations.

C. Interior Communications

12C1. IMPORTANCE OF INTERIOR COMMUNICATIONS

A reliable and easily operated interior communications (IC) system is essential to the functioning of the battle organization. Through the IC system, command control directs all elements of the ship's combat power; primary control stations pass orders and reports; and subordinates exchange information necessary to perform their duties.

The signals transmitted in IC systems include (1) verbal transmission by voice or legible words, (2) nonverbal audible or visible signals (such as alarms) intended for personnel, and (3) electrical signals (such as synchro signals or relay currents) to be received and utilized directly by electrical or mechanical devices. This section is not concerned with the third type of signal, which has been already discussed in connection with the functioning of fire control systems.

12C2. VERBAL IC SYSTEMS

The number and complexity of verbal IC systems aboard a ship depend upon its size, type, function, and communications needs. However, on all ships the systems are organized along parallel lines, and similar code designations are used, so that, for example, the 1JV sound-powered phone circuit aboard a light cruiser has its counterpart (through somewhat simplified, because the ship is itself less complex) aboard a destroyer, and is almost identical with its similarly designated circuit aboard another ship of the same class.

The principal verbal IC systems aboard combat ships that will be studied in this section are:

1. Battle (sound-powered) telephones.

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2. Announcing (MC) systems both one-way and multichannel.

Other systems are also used, but are relatively less important in weapons operations. These include the ship's service dial telephone, voice tubes, messengers, pneumatic tubes (to carry written messages), Teletype systems (with large-screen projection of the printed tape at the receiving point), Telautograph, special telegraph systems like the engine room telegraph, and closed circuit television.

12C3. BATTLE (SOUND-POWERED) TELEPHONE SYSTEMS

The most important IC system is the sound-powered battle telephone system, in which the speaker's voice creates the current which transmits the message. No outside source of power is required. This system is therefore more reliable in emergencies than any which depend upon externally supplied electric power.

Battle telephones are set up as groups of connected stations rather than as individual stations. When a telephone is plugged into its jackbox it is automatically connected with all other stations on that circuit which are at that time plugged in. The connected groups are called circuits. Circuits in turn are organized into systems: (1) primary, (2) auxiliary, and (3) supplementary.

There is a standard method of designating, by symbols, every circuit in each of the three systems. The primary battle telephone system uses circuit designations JA to JZ. Typical examples are:

JA—Captain's battle circuit
JC—Ordnance control circuit
JK—Fuse setters' circuit
JW—Range circuit

Numerals preceding the two-letter designations (2JW) are used to identify individual circuits with the same function but pertaining to different batteries (or similar subdivisions for nonweapons circuits). Numerals following the two letters indicate stations on the circuit. For example, 2JW2 refers to a particular battery's range circuit, station 2.

Auxiliary battle telephone circuits are assigned circuit numbers similar to their primaries, but preceded by the letter X; for example, XJA for the captain's auxiliary battle circuit, or X1JC for the auxiliary turret control circuit. Circuits of the supplementary telephone system are assigned designations such as X1J and X2J through X407J.

12C4. PRIMARY CIRCUITS

Primary circuits are the main channels of communication for controlling armament, engineering, damage control, and maneuvering of the ship. When the ship is at general quarters, each station on a primary circuit is normally manned by either the officer in charge of the station, one of his assistants, or a telephone talker reporting to the officer in charge of the station. These men normally wear headsets, so that they may maintain a continuous watch on the lines. In addition to those headsets which are plugged into individual circuits, control officers may wear headsets which are connected to selector switches which enable them to cut into any one of several circuits in which they are directly interested. At other stations control officers may have available to them handsets with which they may intermittently communicate on one or more circuits normally covered for them by talkers. (A talker is an enlisted man assigned as a principal duty to man a battle phone station for an officer at a control station.)

All primary circuits for the ship's armament can be controlled and interconnected by switchboards in the plotting rooms, as well as by selector switches. With these switchboards, control circuits may be shifted to parallel the transmission of information or orders by synchro. They also make it possible to tie circuits together, as may be done during wartime cruising when not all stations are fully manned, or to provide emergency communication facilities between stations not normally connected, and to isolate circuits or individual stations when necessary as, for example, in case of casualty.

In the plotting room a Fire Control Technician is normally assigned to the fire control switchboard, and an I.C. Electrician to the battle telephone switchboard. When control is switched from one station to another, they reset both boards. This means changing over the synchro and indicator circuits of one or more batteries to connect them to one or more other batteries. The ordnance control telephone circuit (JC) must be switched likewise. This is done by making cross-connections on the switchboards. The crew in the plotting room takes care of the plugging and switching involved. Personnel in the director and at the guns know what is going on, but they play no part in the actual switching operation. The I.C. switchboard crew also takes care of interconnecting other affected circuits as required.

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12C5. AUXILIARY, SUPPLEMENTARY, AND EMERGENCY CIRCUITS

The auxiliary battle telephone system is a standby system which duplicates the most important primary circuits and is intended for use in case the latter become inoperative. It does not have switchboards. Therefore, in case of a casualty at the switchboard, the auxiliary circuits may still be available for use. The wiring of the auxiliary circuits is separated as much as practicable from the wiring of the corresponding primary circuits to prevent battle damage to both circuits. As the auxiliary battle telephone circuits are not ordinarily continuously manned, they are generally equipped with handsets and receptacles to connect headsets, when necessary.

Supplementary circuits are those either not important enough or not extensive enough to be included in the primary system. Most supplementary circuits include only two or three stations. They are equipped with handsets and are usually accompanied by circuit-E buzzer systems. (See article 12C7.) In mounts and turrets most supplementary circuits are concerned with ammunition service. Thus the supplementary circuit found in 5-inch enclosed mounts is the X17J, which connects the top and bottom of the lower ammunition hoists. Turrets may have more elaborate supplementary telephone circuits for internal use. The Salem class 8-inch turret has nine supplementary circuits. One of them connects the turret officer with gun positioning and sight-setting personnel, and the others connect various stations of the ammunition supply system with the gun captains and turret officer. Supplementary battle circuits have no switchboards, but selector switches can be used to interconnect some supplementary circuits or to tie them into primary circuits.

Emergency sound-powered systems consist of portable telephone lines with sound-powered telephones attached. This emergency equipment is generally kept on reels located at strategic points throughout the ship and the phones may be unreeled to serve as a standby in case of failure of normal sound-powered communications during battle.

12C6. BATTLE ANNOUNCING (MC) SYSTEMS

There are two characteristic types of battle announcing systems. One is the central amplifier system, consisting of one or more microphones and loudspeakers. The other type is the intercommunications ("intercom") system, designed to provide two-way transmission of orders and information between stations. Both types use electronic amplification.

The main announcing system for the ship is the 1MC, or general announcing system operating under the authority of the Officer Of the Deck, over which word can be passed to all parts of the ship.

The 21MC is the captain's command announcing system. This system provides for two-way transmission of ship control orders and information between interested key stations, including the primary and secondary conning stations, battery control stations, air defense stations, combat information center, and others. Other electronic amplification systems of interest to weapons personnel are listed in table 12-1.

Table 12-1.—Weapons Announcing (MC) Systems.

CIRCUIT	SYSTEM	USED PRIMARILY ON
	Central Amplifier Systems	
29MC	Sonar Control Information	Surface Ships
46MC	Aviation Ordnance and Missile Handling	Aircraft Carriers
	Intercommunications Systems	
27MC	Sonar Control	Submarines
30MC	Special Weapons	Aircraft Carriers
32MC	Weapons Control	Surface Ships
47MC	Torpedo Weapons Control	Submarines

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Central amplifier type MC systems have the advantage over telephone communications in that they transmit orders or information simultaneously to all personnel at a station. Since, however, their continued use results in excessive noise levels, they are normally employed only for urgent and simple messages.

Intercoms, like general announcing systems, have the advantage of attracting the attention of all hands at a station simultaneously. They similarly have the disadvantage of raising noise levels, although this disadvantage is lessened by the fact that messages are heard only at the one station addressed. They are used to parallel telephone communications in the case of urgent and short messages, and are also frequently used to regain communications when a station fails to answer on a battle telephone circuit.

The sound-powered telephone system has been adapted, in certain cases, so that when desired, the voice on the sound-powered telephone circuit can be electronically amplified and put through speakers. Such a combination of the battle telephone with electronic amplification has the advantages of an intercom and a telephone. It is used primarily at battery control stations for communications to gun mount personnel. This has replaced MC systems in these stations on most all ships.

12C7. SIGNAL SYSTEMS

Telephone and announcing systems are primarily voice communication systems. Besides these, modern combat ships are equipped with several systems of signals for special purposes:

1. Train Warning Signals (TW). Safety regulations require that before any turret or enclosed mount is moved in train, a warning signal must be sounded so as to inform personnel to keep clear. The only exception is that the signal need not be sounded during general quarters. The train warning signal circuit is independent of all other IC circuits, and consists of a pushbutton control switch at the mount captain's station, bells outside the mount, and the necessary wiring and power supply.

2. Call-signal System (circuit E). The call-signal system (circuit E) parallels the supplementary battle telephone circuits and voice tubes. It is not used independently; it always parallels a voice communication line. It consists of power-supply units, pushbutton switches, and buzzers or bells.

3. Cease-firing Signal. The order to cease fire is normally given by sounding a special signal consisting of a loud, low-pitched, penetrating buzz produced by an electrically driven device, in addition to transmitting the order in words. This signal is usually transmitted over independent reproducers at the mounts or turrets. In certain machinegun systems this circuit can be so interconnected with the headsets of gun crews' telephones that they will hear the cease-fire signals in their phones as well as over the reproducers installed at the mounts.

4. Salvo Signals. The salvo signal is a variable-pitch buzz produced electrically by special apparatus. Salvo-signal reproducers are installed where they can be heard by the crew in the gun compartments. There is no salvo-signal circuit for the machinegun battery.

12C8. ALARMS

The IC system includes a number of alarms for use in alerting or signaling personnel with regard to a specific dangerous condition. The number and type of alarms vary with type of ship. Four main alarms are:

1. Collision alarm
2. Chemical attack alarm
3. General alarm
4. Sonar alarm

The above listed alarms are connected into the ship's 1MC circuits. The closure of an alarm contact maker anywhere in the ship will sound any one of the four alarm signals over all circuit 1MC loudspeakers. The alarms are listed in the order of their priority which is automatically controlled by relays in the audio amplifier. Any alarm takes priority over voice announcements.

If an alarm is being sounded and a higher priority alarm contact maker is closed, relays operate to cut off the alarm signal being sounded and cause the higher priority alarm to be sounded instead. Conversely, the closure of a low priority alarm contact maker has no effect on a high priority alarm that is being sounded. The system operates to generate the alarm signals as long as the alarm contact maker is held closed (except for general alarm which is sounded for a predetermined 15-second interval after momentary closure of the general alarm contact maker.)

A few independent alarm systems used on board ship are:

1. Emergency steering alarm

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2. Fire alarm
3. Carbon dioxide (CO_2) alarm

12C9. CLOSED-CIRCUIT TELEVISION

One of the most prevalent Navy uses of closed-circuit television (TV via cable) is data display. Instantaneous and accurate data are sent by a TV camera mounted in CIC to receivers in weapons control, commanding officer's tactical plot, flag plot, and the air control section of CIC via a high resolution, closed-circuit television system. The addition of television equipment has done much to eliminate the time-consuming link formerly associated with the transfer of bogey data by sound-powered telephones. Telephones are still used for action commands and to provide an audio backup for visual information. They continue to be the information link to antiair warfare stations that do not have a critical evaluation assignment.

Pilot Landing Aid Television (PLAT) has been installed aboard almost all U.S. Navy aircraft carriers. This closed-circuit television system aids in landing aircraft, and records landings on videotape for immediate playback and analysis by pilots. Figure 12C1 shows a sequence of photographs taken from a shipboard television monitor displaying a jet carrier landing. A television camera mounted in the center line of the carrier deck spots the plane at the beginning of its landing approach, and follows it to the touchdown. A second TV camera on the carrier's superstructure then takes over. Crosshairs on the monitor assist the landing signal officer in talking the pilot down to a safe landing. Minute-by-minute records of time, air speed, wind velocity, and flight number are shown on the dials at the top of the screen. Audio recordings of the conversations between the pilot and the landing signal officer are made on the same tape along with the video information. The tape is a complete record of each landing, day and night.

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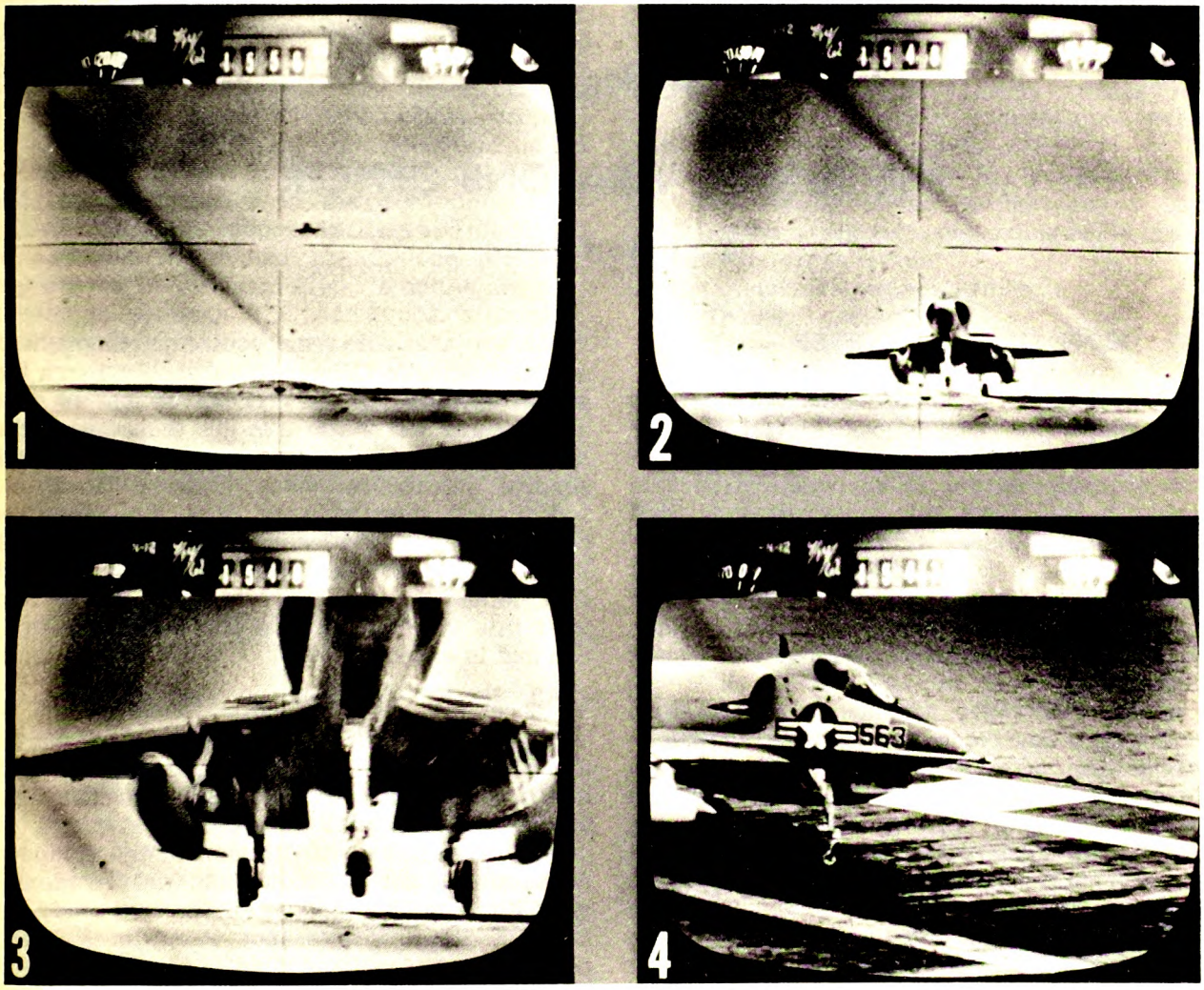

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Figure 12C1.—Pilot Landing Aid Television (PLAT) showing a videotaped jet carrier launching.

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CHAPTER 13

THE JUNIOR WEAPONS OFFICER

A. Introduction

13A1. SCOPE OF THIS CHAPTER

This chapter is not so much the finale to this textbook on "conventional" naval weapons as it is an introduction to the first stage of your probable career in the weapons department of a U.S. Navy ship, regardless of what aramament it carries. It introduces to you some of the practical day-to-day details that fill a naval officer's life on board ship. This chapter is principally focused on what you as a junior officer in the weapons department can expect to experience.

In the remainder of this chapter, assume in all cases that we are discussing a surface combat ship other than an aircraft carrier. Where there's a choice between a large ship and a small one, assume a small one like a destroyer or destroyer escort. (Exceptions to these assumptions will be indicated or apparent from context.)

13A2. KNOW YOUR SHIP

Aboard many ships, one of the first things the commanding officer might tell a new officer to do is perform some orientation assignment like locate and map on a large sheet of paper all the watertight doors on the ship, or trace certain communication lines. Some commanding officers put new officers through a fairly detailed and time-consuming "geographical" orientation course of this kind. This is not arbitrary. If your CO doesn't tell you to do it when you report aboard, you should do it on your own. You should get to know the ship's layout and characteristics even better than you knew the dwelling you lived in ashore—unless you traced all the plumbing and utility lines at home. This information isn't hard to find—it's in the ship's damage control and general information books which are available from your department head or the Engineer Officer. You should learn the ship's organization and procedures just as soon as you are able—you can get these from the ship's organization manual, from the ship's general information book, from NWP 50(A), and from other sources that the executive officer or your department head can provide if you ask for them. Get the ship's tactical data folder and the appropriate NWPs to find what this type of ship, and this particular ship, can and is expected to do.

13A3. KNOW YOUR DEPARTMENT

Don't forget the department of which you're a member. Get to know the watch, quarter, and station bill, and the relevant parts of the ship's organization manual on which it's based. If you're assigned to a division in the weapons department, get to know just what material your division is responsible for, and study the Current Ships Maintenance Program (CSMP), ordnance history, and OrdAlt files—and read the logs too—so that you'll at least have some acquaintance with the armament aboard. Find out also about the training program—how it works, what records are being kept, the training policies of the weapons officer, the commanding officer, and the executive officer.

There is much more to be said on the points of self-study, initiative, and inspiration than there is space for here. Remember especially that to do your job, you need self-training; for this you need initiative; and if you have initiative, it will seldom be necessary for your superiors to tell you what to do, because you'll know it, and do it.

13A4. THE JUNIOR OFFICER

Soon after reporting aboard ship the commanding officer will assign you a billet (a job

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title). If you are assigned to the weapons department your billet could be anything from a junior division officer to assistant weapons officer. You would most likely be assigned as a departmental assistant, such as fire control officer. (Other assistants are listed later in article 13A6). There is a good chance you will be a division officer as well, depending on the number of officers in the weapons department, and the organization of the department. The division officer's responsibilities are discussed in articles 13A12 and 13A13. The practical aspects of the division officer's duties are discussed in sections B, C, and D of this chapter.

By understanding the weapons officer's duties and responsibilities you will better understand your own. Your specific duties may be a portion of the weapons officer's duties or, as assistant weapons officer, you would be involved with nearly all the duties of the weapons officer. In any case you need to understand them eventually so you will be prepared to become the weapons officer yourself some day.

13A5. THE WEAPONS OFFICER'S RESPONSIBILITIES

The weapons officer directs activities of the weapons department; advises and assists the commanding officer on weapons operations and problems; directs operation, maintenance, and repairs of all weapons and weapons direction and control equipment; supervises care, handling, stowage, and use of explosives; interprets and applies ordnance regulations and directives issued by technical bureaus and higher command; establishes a weapons department training program, organizing department drills and exercises; ensures performance of deck seamanship operations such as anchoring, mooring, fueling at sea, cargo loading, and care and maintenance of equipment connected therewith; and inspects spaces assigned, including exterior surfaces of the ship, to ensure proper care and maintenance. The weapons officer's responsibilities are also discussed in general terms in chapter 1. In chapter 7 they are discussed with regard to spotting and shore bombardment; and chapter 12 discusses them in connection with battle organization.

13A6. ORGANIZATIONAL RELATIONSHIP OF THE WEAPONS OFFICER

The weapons officer reports to the commanding officer for the employment and readiness of the ship's armament, fire control systems, sonar system, and deck seamanship equipment. These are operational responsibilities.

The weapons officer is responsible to the executive officer for administrative matters.

Now, how about those directly responsible to the weapons officer? You already know that on most ships the fire control officer is not the only officer assistant that the weapons officer has. The weapons officer can have any or all of the following assistants, depending on the type of ship and its organization:

1. Assistant weapons officer
2. Gunnery assistant
3. First lieutenant
4. Gun battery officer
5. AA control officer
6. Fire control officer
7. Missile officer
8. CO of Marine Corps detachment
9. A/S officer
10. Nuclear weapons officer
11. Warrant officers
    a. Fire control gunner
    b. Ordnance gunner
    c. Missile ordnance gunner
    d. Missile test and repair officer
12. Division officers

The functions of some of the primary departmental assistants mentioned above are described at length in the following articles. The names give you an indication of their areas of responsibility. Under them are the division officers (though on smaller ships or where the allowance is limited some of the departmental assistants may double as division officers.) One of the departmental assistants usually functions as assistant weapons officer when necessary. He has much the same relationship to the weapons officer as the executive officer has to the ship's commanding officer.

13A7. FIRST LIEUTENANT

The first lieutenant supervises and directs the deck force in performance of seamanship functions and evolutions; gives direct commands, or delegates responsibility for immediate supervision to the ship's boatswain or petty officers, during various evolutions such as mooring, docking, anchoring, fueling, or transferring personnel and cargo at sea; assigns boats and boat crews in compliance with ship's boat schedule; supervises readiness of boats and survival equipment by frequent inspection, and orders

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repairs or replacements as required (with the exception of power boat engines and engine compartments, which are the responsibility of the engineering department); directs preservation of weather decks, ship's exterior, running gear, ground tackle, and bosun's stores; arranges for the training of deck divisions, scheduling drills and classes in deck seamanship, boat handling, and marlinespike seamanship; recommends transfer, reassignment, and promotion of deck personnel; directs the preparation of weekly, monthly, and quarterly reports as required; and maintains files and records for reference by deck divisions.

13A8. FIRE CONTROL OFFICER

The fire control officer directs the division of the weapons department concerned with operation, maintenance, and repair of weapons and guided missile weapons control equipment and systems; assigns personnel to operation and maintenance duties on all weapons control equipment and systems; establishes and supervises training programs, scheduling classes and drills; supervises division personnel, administering liberty, leave, and transfer; and approves assignment of weapons control personnel to the watch, quarter, and station bill.

13A9. MISSILE OFFICER

The missile officer directs the operation, maintenance, and repair of guided missile installations and associated equipment; establishes and supervises a training program for guided missile personnel, scheduling drills and organizing firing practices; ensures compliance with maintenance and repair instructions; inspects missiles and missile battery, and supervises major repair tasks and alterations; directs operation and maintenance of guided missile launchers, loading systems, and loading/launching control systems; directs assembly, tests, and maintenance of guided missiles and components; interprets current directives from technical bureaus and higher commands concerning guided missile battery doctrine and regulations; and supervises preparation of the required records and reports.

13A10. A/S OFFICER

The A/S officer directs employment, operation, and maintenance of all antisubmarine equipment in the weapons department; assists the commanding officer during antisubmarine search and attack; directs the operation, care, and maintenance of all antisubmarine equipment, including search and attack sonar, fire control equipment, weapons, attack aids, torpedo countermeasures, and underwater communications equipment used in identification and classification of submarines; supervises and trains personnel assigned to the department or to antisubmarine stations in sonar search techniques, submarine contact evaluation, operation of equipment, and antisubmarine doctrine; and advises superior officers on all matters concerning antisubmarine operations.

13A11. NUCLEAR WEAPONS OFFICER

The nuclear weapons officer plans and executes maintenance and repair of nuclear weapons, components, and test and handling equipment assigned; directs and coordinates functions of the nuclear weapons division; directs overall functions of assembly teams; ensures that prescribed quantity and quality of nuclear weapons is maintained; directs a training program within the division; ensures that adequate safety and security measures are carried out; and supervises maintenance of records and preparation of reports required.

13A12. THE DIVISION OFFICER'S GENERAL RESPONSIBILITIES

In general terms, the division officer is responsible for carrying out the policies of the commanding officer as amplified by the executive officer and department head. He is responsible under the head of department for the organization, administration, and operations of his division. The division officer reports to the head of department for the performance of his assigned duties. All personnel in his division report to him; if junior division officers are assigned they also report directly to him.

13A13. SPECIFIC AREAS OF RESPONSIBILITY

In more specific terms, the division officer's responsibilities can be divided into six main categories:

1. Organizational responsibilities
2. General administration
3. Personnel administration
4. Material responsibilities
5. Training
6. Miscellaneous

In the next three sections we'll discuss practical aspects of these responsibilities of the division officer.

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B. Organization, Administration, Personnel, and Miscellaneous

13B1. INTRODUCTION

From the six areas of division officer responsibility mentioned in the preceding section, we'll attempt to concentrate on those aspects that specifically involve the weapons department and the ship's armament. This text is primarily concerned with these aspects rather than with those that apply to all departments and officers in general. If we do this, it becomes clear that of the six, the two areas that are most peculiar to the weapons department and the ship's armament are material and training. These two are therefore taken up in detail in the next two sections. In the present section, we discuss, rather more briefly, the four areas which, though important, are also of more general application in all departments, not merely the weapons department. These are: organization, administration, personnel, and miscellaneous responsibilities of the division officer. So far as possible we'll concentrate on those aspects of these areas that are specifically applicable to the weapons department.

13B2. DIVISION ORGANIZATION

Figure 13B1 illustrates schematically the organization of a more or less typical fire control division (F or "Fox" division) aboard a destroyer (DD).

Many of the elements of this organizational scheme you have seen before. You already know that under the department head are the division officers. The division officer will generally be an ENS or a junior LTJG. If he has a junior division officer it will most likely be a junior ENS. On a large combat ship (such as a cruiser or aircraft carrier) the division officer will generally be a LT or LTJG assisted by a junior division officer with a rank of ENS or possibly LTJG plus one or two warrant gunners to assist with technical problems of fire control and weapons operation and maintenance.

The leading petty officer in the division is usually a Chief Fire Control Technician (FTC). The remainder of the division consists of three watch sections, each under a section leader. Section leaders function as military superiors as well as technical supervisors.

During peacetime, personnel on board are frequently lower in rate than the allowed billets call for. Where the divisional organization chart calls for a chief petty officer, quite often you will find a First Class petty officer in the slot. The same holds true all the way down the line. A Second Class petty officer often fills the billet of a First Class. Very often you will find strikers performing the duties of Third Class petty officers.

In figure 13B1 the second section is broken down in detail; the other two sections are set up similarly, except that the distribution of rates and ratings is not identical. At times there are not enough crewmen aboard to fill all the allowed billets. Depending on the personnel on board and their qualifications, a billet may be filled by a man with a lower rate or a related but different rating. For example, a Gunner's Mate Second Class may fill a Gunner's Mate First billet or a Fire Control Technician's billet.

ST1 stands for Sonar Technician 1st Class. Sonar Technician is a rating—the designation of a specific group of specialists. First Class is a rate, corresponding to a pay grade. (The distinction is worth remembering.) The ST1 may supervise a Sonar Technician Striker—a nonrated man who is in training for ST G or S Third Class.

The organizational arrangement of personnel which is taken from the ship's organization manual and shown on the watch, quarter, and station bill, is used for administrative purposes, including the assignment of personnel to cleaning stations (as shown in figure 13B1). Personnel are withdrawn temporarily from their cleaning stations for specific evolutions covered by ship's bills, which we'll take up next.

13B3. SHIP'S BILLS

A ship's bill is the method of establishing assignments of ship's personnel to duties or stations for the purpose of executing specific evolutions or accomplishing certain functions. In general, a bill includes the following information:

1. Statement of purpose
2. General information
3. Assignment of responsibilities
4. Statement of organization
5. Assignment of personnel
6. Procedures (See article 13B4.)

Bills are classified as:

1. Administrative
2. Operational
3. Emergency

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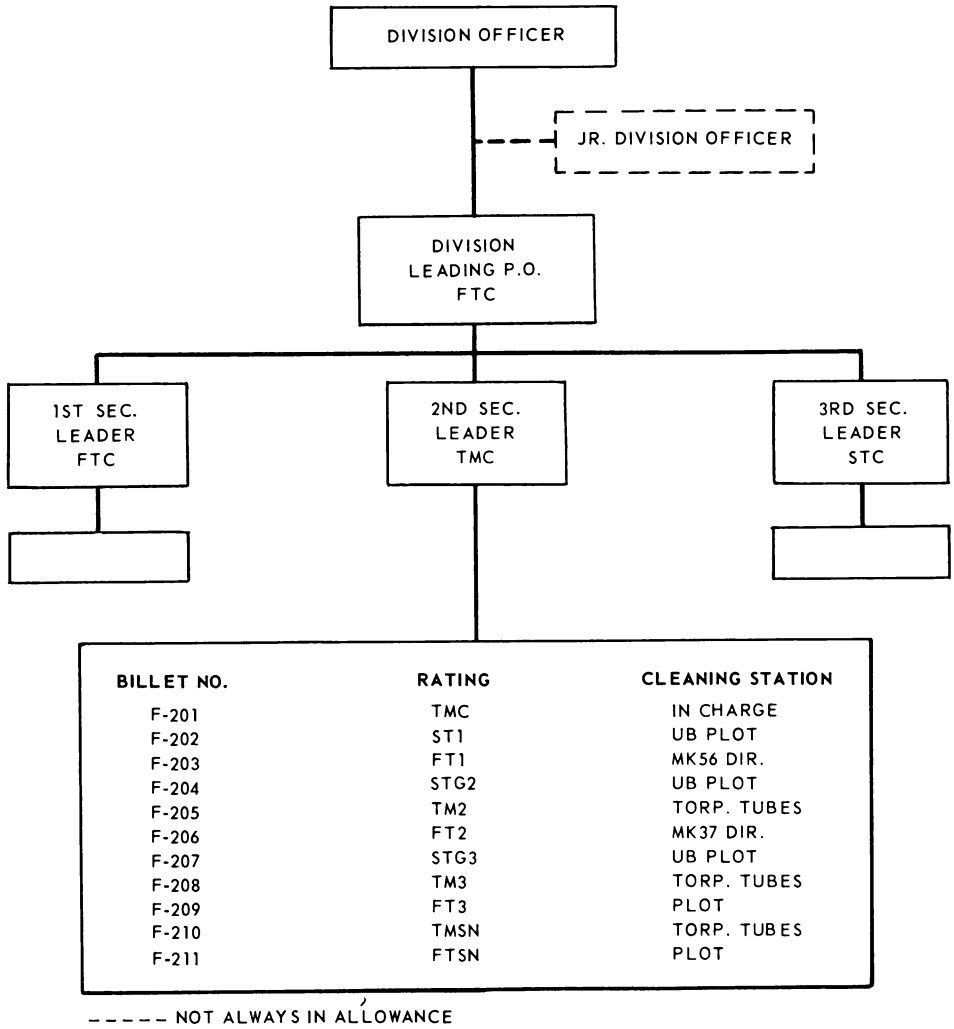

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Figure 13B1.—Organization of F division aboard a destroyer (DD).

Since all officers must be familiar with the ship's organization manual, they must be acquainted with all the ship's bills, even those for which they have no direct responsibility. Table 13-1 gives a partial list of the bills used on a typical destroyer along with the title, purpose, and organizational designation of the officer responsible for preparing it.

Table 13-1.—Summary of Ship's Organizational Bills.

BILL	PURPOSE	RESPONSIBILITY
	To establish procedures and assign duties for:	
Personnel Assignment Bill -----	Assignment or reassignment of officers and enlisted men to billets within depart- ------	Executive officer.

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Table 13-1.—Summary of Ship's Organizational Bills—Continued.

BILL	PURPOSE	RESPONSIBILITY
	ments and divisions of the ship.	
Berthing and Locker Bill	Assigning berthing and locker facilities.	Executive Officer.
Cleaning and Maintenance Bill	Maintenance, preservation and cleanliness of the exterior and interior of the hull, hull fitting, machinery, and equipment.	Executive officer.
Special Sea Detail Bill	Getting underway and returning to port.	Navigator.
Replenishment at Sea Bill	Fueling, rearming, provisioning, or transferring personnel at sea.	First Lieutenant.
Rescue and Assistance Bill	Rendering emergency assistance to persons or activities outside the ship.	Engineer Officer.
Landing Party Bill	Conducting limited field operations, policing during an emergency, and participating in parades and ceremonies.	Weapons Officer.
Visit and Search, Boarding, and Prize Crew Bill	Investigating, salvaging, and taking possession of another ship.	Operations Officer.
Towing Bill	Towing or being towed by another ship.	First Lieutenant.
General Emergency Bill	Controlling the effects of a major emergency or disaster suffered by the ship, such as collision, grounding, internal or external explosion, nuclear contamination, earthquake, storm or battle damage.	Engineer Officer.
Man Overboard Bill	Recovering one man or a small number of men from the water.	First Lieutenant.
Biological and Chemical Warfare Defense Bill	Minimizing the effects of a biological and chemical attack.	Engineer Officer.

13B4. SHIP'S PROCEDURES

Like bills, the term procedures also has a special meaning in this context. A procedure is a written statement of a series of coordinated steps by an organizational unit for the accomplishment of a specific function. Shipboard procedures are classified under one of the following categories:

1. Personnel
2. Accountability
3. Operating

Personnel procedures include such matters as disciplinary measure, leave and liberty, petty officer evaluation, training, how to deal with visitors, the handling of U. S. mail, etc. Accounting procedures cover such matters as material inventories and surveys, and accounting for mess, welfare, and recreation funds. Most of these are set forth in chapter 9 of NWP 50(A), Navy manuals on correspondence and filing, and OPNAV and SECNAV instructions.

Table 13-2 is a partial list (with references) of typical operating procedures aboard a destroyer.

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Table 13-2.—Shipboard Operating Procedures.

TITLE	REFERENCES OTHER THAN FLEET AND TYPE DIRECTIVES
Jettison procedures	Chapter 9, NWP 50(A)
Strip ship procedures	Chapter 9, NWP 50(A)
Scuttling the ship	Chapter 9, NWP 50(A)
Emergency destruction of classified matter	Chapter 9, NWP 50(A)
Steering casualties	Chapter 9, NWP 50(A)
Operations with helicopters	Chapter 9, NWP 50(A)
Fog navigation	Chapter 9, NWP 50(A)
Securing the ship against sea damage	Chapter 8, NWP 50(A)
Cold weather operating procedures	(a) NWP 35 (b) H.O. 551, The Manual of Ice Seamanship
Darken ship procedure	
Security against sneak attack procedure	
Repel boarders procedure	
Dry docking procedures	(a) BUSHIPS Manual Chapter 7 (b) USNR 1948 Art. 0749, 0790, 0791 and 2030
Mediterranean moor procedure.	
Small boating procedure	

13B5. MISCELLANEOUS (COLLATERAL) DUTIES

Besides the assigned departmental duties and the regular military duties of the division officer (such as underway watches, in-port watches, and GQ assignments), all officers are assigned collateral duties (secondary duties). These include serving on committees and boards (such as the audit board, the recreation committee, courts-martial boards, and officer candidate examining boards) and performing some special function such as intelligence officer, photographic officer, classified material control officer, or legal officer.

On a destroyer a division officer might expect on the average to have two or three such collateral assignments. On ships with more personnel, like cruisers and carriers, some of these duties (such as legal officer or education officer) may be assigned as primary duties.

C. Material

13C1. SCOPE OF THIS SECTION

The division officer has, as the preceding section pointed out, a great deal to do that is more a part of his broad responsibilities as a naval officer than a part of his narrower specialty.

The preceding section took up the broad responsibilities; this section is concerned with one of the main aspects of his specialty—material. (The other aspect—training—is taken up in the section following this one.)

13C2. INTRODUCTION TO NAVY MATERIAL MAINTENANCE SYSTEM

As a naval officer aboard ship you won't normally have much to do with equipment

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design. Although important new design ideas and innovations in material employment have come from the fleet in the past, your primary concern with material will be in keeping the equipment you are responsible for in tip-top condition. This is material maintenance. The Navy has spent considerable time and effort on material maintenance. As you remember from chapter 1, two major organizational components of the Navy Department—Bureau of Weapons and Bureau of Ships—are primarily concerned with maintenance of shipboard material.

On board ship, maintenance work can be considered as falling into three more or less distinct kinds of activity—upkeep, repairs, and alterations.

Upkeep in general includes preventive maintenance operations—lubricating, inspecting, adjusting, exercising, painting, testing, corrosion-proofing, and so on.

Repairs include troubleshooting, replacing, and restoring equipment or parts to serviceable condition after there has been a material failure or malfunction. It makes no difference what has caused the failure, whether it is wear, rust or corrosion, accident, personnel error, failure of some other part or equipment, or enemy action.

But repair does not include any change you may make to improve a piece of equipment over its original design. Such a change is an alteration. Navy ordnance gear may not be altered except with the approval of the Bureau of Weapons.

Most maintenance work aboard ship is accomplished by the ship's force—the naval personnel on the ship. But periodically every ship is assigned tender availabilities and a yard availability. This means that the ship can tie up to a tender or go into a yard for a specified period and have work done that is beyond the capacity of the ship's force or that cannot be done while the ship is operational. Such work is major repair or overhaul of hull, machinery, or armament, for which the ship's force hasn't either the tools or the skills. Examples of such work on weapons department installations are substitution of a new director for an old one, or lifting out a 5"/38 twin mount to replace parts of the training circle or roller path.

To keep track of all maintenance work on the ship's ordnance gear, the department head and leading Gunner's Mate use checkoff lists, work logs, the CSMP, and the Ordnance Machinery History. A Standard Navy Maintenance and Material Management Program will be developed and implemented Navy-wide by approximately 1 January 1965 for aviation and approximately 1 January 1966 for surface forces. In this age of sophistication and weapon system complexity, more accurate and timely measures of material readiness are mandatory. Until this new maintenance management system is implemented you will continue with the present system. You'll learn about checkoff lists and work logs in the next article. The Ordnance Machinery History is a compilation in a card file of past equipment operation (including casualties) and present condition, made up from the logs. Every piece of gear installed on the ship is included in the machinery history. But the source of primary importance for scheduling yard and tender work is the CSMP.

The CSMP is what you might call the future ordnance machinery history. It details, equipment by equipment, the work that needs to be done. Unlike the machinery history, only those equipments are listed in CSMP that actually require work to be done on them.

Physically, the CSMP is a file of card forms about 4 x 6 1/2 inches. There are two kinds of forms—one for repair work, one for alterations. They are illustrated in figure 13C1. The repair cards describe needed repair work, with one repair item per card. The alteration cards deal similarly with alterations. The CSMP lists all repairs and alterations, not just the ones that are too big for the ship's force. From these cards are made up the work requests which ultimately go to the yard or tender.

The junior weapons officer should become familiar with the CSMP as soon as possible, and see that entries pertaining to equipment for which he is responsible are promptly made. Whenever a piece of equipment requires repair, a complete brief of the existing condition should be drawn up, including an analysis of the deficiency and an estimate of the work necessary to restore the equipment to serviceable condition.

When authorizations for alterations are received from the Bureau of Weapons prompt entry should be made in the alteration CSMP. Thus, when a ship is scheduled for repair ship availability or shipyard overhaul, work lists can be quickly compiled. This procedure is discussed later in this section.

13C3. UPKEEP

Most modern ordnance equipment is extremely complex and requires frequent periodic

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NAVORD Form 2033 (New 5-51) REPAIR CARD Stocked in CDS

MACH. / ELEC. / HULL / X ORD.	MOUNT 51 (INDEX SUBJECT)		574 (INDEX NO.)	DEF.	ROU.	X (URGENT)
LOCATION: FRAME 80 - 01 LEVEL - CENTERLINE		DATE LISTED: 4/15/56	TITLE	S. FC.	REP. S.	N. YD.: X

WORK REQUIRED—WORDED AS A JOB ORDER (AMPLIFYING REASONS MAY BE GIVEN)

REPLACE GUN BARRELS (2); SER. NOS. 7183, 7184.
REASON - WORN OUT; ESR 5100 RDS.

STATUS OF MATERIAL: AVAILABLE AT NAVY YARD	APPLICABLE BLUEPRINTS		
BD. I & S ITEM NO.	FORCES AFLOAT MAT. INSPECTION	QUAR. 194	ITEM NO.
SHIP'S REQUEST FOR AUTHORIZATION FILE NO.: 101011 Z		OF: APRIL 1956	
AUTHORIZING REFERENCE: COMCRU DESPAC 141925 Z		OF: APRIL 1956	
JOB ORDER NO.: 123/56	PERCENT COMPLETION ON		
DATE WORK STARTED: 12 MAY '56	MAN-HOURS TO COMPLETE: 105	DATE COMPLETED: 14 MAY 1956	ENTERED IN MCH. HIST. OR OFFICE LOG.: 20 MAY 1956 MRM

A

ALTERATION CARD NAVORD FORM 2034 (NEW 5-51) Stocked in CDS

MACH. / ELEC. / HULL / X ORD.	MK 37 DIRECTOR #51 (INDEX SUBJECT)		571 (INDEX NO.)	DEF.	X (ROU.)	URGENT
LOCATION: FR. 95, 06 LEVEL CENTERLINE		DATE LISTED: 1/23/56	TITLE	S. FC.	REP. S.	N. YD.: X

WORK REQUIRED—WORDED AS A JOB ORDER (AMPLIFYING REASONS MAY BE GIVEN)

ACCOMPLISH ORDALT 2607
REASON: INSTALL SAFETY LATCH ON POINTER'S & TRAINER'S HANDWHEEL BRACKETS

STATUS OF MATERIAL: ABOARD	APPLICABLE BLUEPRINTS: SEE ORDALT INSTRUCTIONS		
BD. I & S ITEM NO.: —	FORCES AFLOAT MAT. INSPECTION: —	QUAR. 19: —	ITEM NO.: —
SHIP'S REQUEST FOR AUTHORIZATION FILE NO.: —		OF: —	
AUTHORIZING REFERENCE: ORDALT 2607		OF	
JOB ORDER NO.: 110/56	PERCENT COMPLETION ON		
DATE WORK STARTED: 2/15/56	DATE COMPLETED: 2/22/56	REPORTED TO BUREAU VIA TYPE COMMANDER: YES 2/23/56	ENTERED IN MCH. HIST. OR OFFICE LOG.: 2/23/56 MRM

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Figure 13C1.—CSMP cards. A. Ordnance Repair Card. (blue) B. Ordnance Alteration Card. (pink)

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check, test, lubrication, and adjustment to keep it in first-class operating condition. This routine, day-to-day, week-to-week work is called preventive maintenance, because it's aimed to discover and eliminate possible sources of trouble before trouble actually occurs.

The Bureau of Weapons furnishes, with each ordnance installation, publications which outline maintenance procedures. These publications (described in chapter 1) are readily available, but it is the junior officer's responsibility to see that the procedures outlined in them are followed by the Gunners' Mates, Fire Control Technicians, SonarTechnicians, Torpedomans' Mates, and all other ratings and personnel under their supervision.

Type commanders issue checkoff lists which detail the items of work that are to be done daily, weekly, monthly, etc. Work logs (daily or weekly records) are kept on each piece of ordnance equipment. The junior officer can use these to quickly check the work accomplished each week. He should not, however, be satisfied with paperwork checks. The junior officer should get around his spaces during working hours, find out what his men are doing, what items or pieces of gear are troublesome, and what can be done to overcome the difficulties. He can also learn much about his equipment if he is present while checks, tests, cleaning, and lubrication are going on.

Paperwork is part of the upkeep job. It is the junior officer's responsibility to see that the ordnance history and the logs on which it is based, for the equipment under his cognizance, are complete and up to date. A complete record for each piece of equipment includes its mark, mod, serial number, nameplate data, and all casualties, repairs, and alterations. Thus the maintenance and alteration status of the various batteries can be determined easily by examining the record. A specimen ordnance history card is reproduced in figure 13C2.

Most of the information which is entered into the machinery history is obtained from the battery and fire control logs. Battery logs, which are usually maintained by the senior petty officer in charge of each type of equipment, under the direct and close supervision of the division officers, show the work accomplished on the equipment, test results, alignment data, etc. It is a painstaking task to ensure that the logs are properly kept up day by day, but only constant checking will result in a proper and complete history. Such entries as "routine tests carried out" are better avoided. It is especially important that logs and records should be carefully kept during overhaul periods (when equipment is under going the largest number of changes and repairs), even though at this time it is most difficult to do so. Such occasions coincide with leave periods, and officers remaining aboard double up to cover all billets.

13C4. REPAIRS

In the formal language of Navy Regulations a repair is defined as "Work necessary to restore a ship or article to serviceable condition without change in design, materials, number, location, or relationship of the component parts."

Repairs are divided into three classes according to the agency performing them: i.e., ship's force, repair ship or tender, or shipyard. Quite naturally, the extent of repairs that can be accomplished by ship's force on small ships is limited by a lack of facilities and personnel. A repair ship or tender has more elaborate repair facilities and personnel experienced in repair work, and can accomplish most work not of a major nature. The shipyard, of course, is capable of handling any major repair item.

There is a sort of twilight zone between repairs and alterations in which belong certain repair operations which involve more than merely restoring the equipment to efficient operating condition according to its original design. Such an operation might be, for example, replacing a part with one of different material or of more efficient design, or strengthening of parts, or making minor changes to prevent recurrence of certain casualties or to prevent damage to the ship's structure. These are called "alterations equivalent to repair." In any case, alterations equivalent to repair must never involve any increase in weight.

13C5. ALTERATIONS

To quote Navy Regulations again, an alteration is: "Any change in the hull, machinery, equipment, or fittings which involves a change in design, materials, number, location, or relationship of the component parts of an assembly regardless of whether it is undertaken separately from, or incidental to, or in conjunction with repairs." No alteration may be made to any ship or article on board until specifically authorized by the Bureau concerned.

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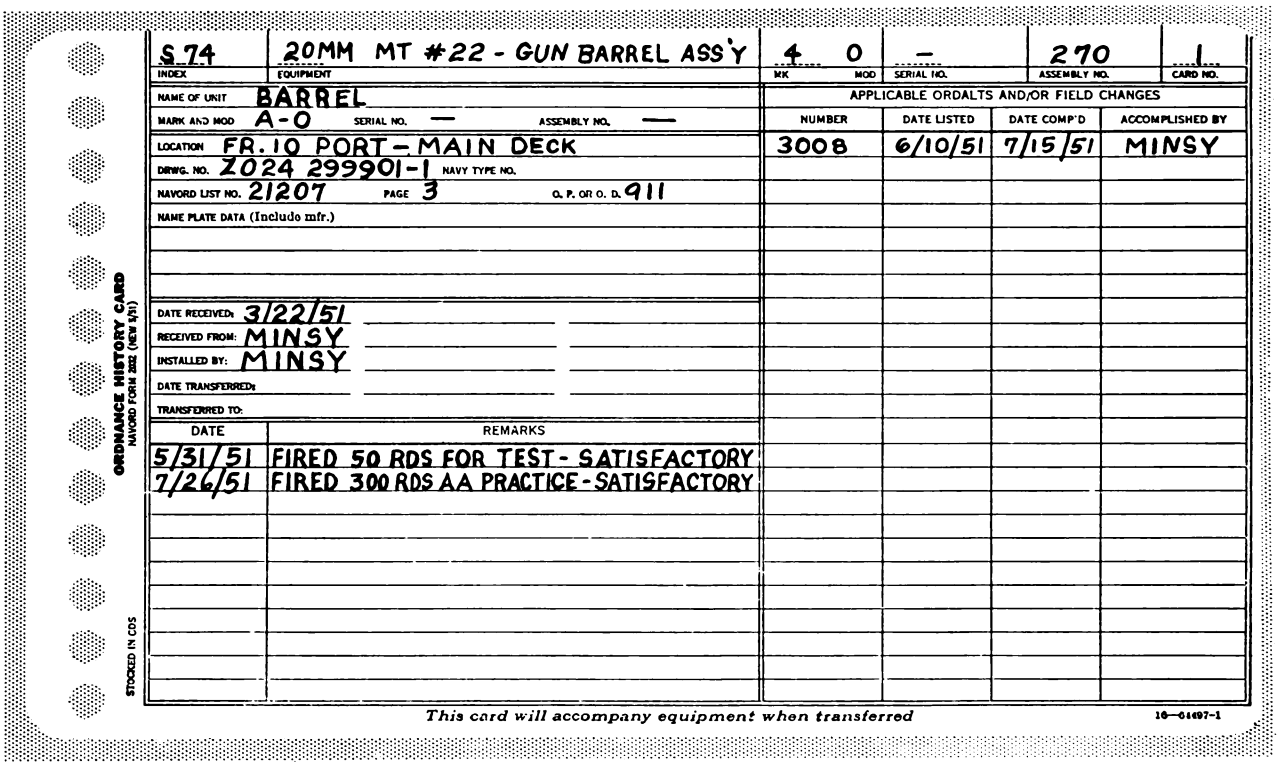

S 74	20MM MT #22 - GUN BARREL ASS'Y	4	0	–	270	1
INDEX	EQUIPMENT	MK	MOD	SERIAL NO.	ASSEMBLY NO.	CARD NO.

NAME OF UNIT BARREL

MARK AND MOD A-0 SERIAL NO. — ASSEMBLY NO. —

LOCATION FR. 10 PORT – MAIN DECK

DRWG. NO. Z024 299901-1 NAVY TYPE NO.

NAVORD LIST NO. 21207 PAGE 3 O. P. OR O. D. 911

NAME PLATE DATA (Include mfr.)

DATE RECEIVED: 3/22/51

RECEIVED FROM: MINSY

INSTALLED BY: MINSY

DATE TRANSFERRED:

TRANSFERRED TO:

DATE	REMARKS
5/31/51	FIRED 50 RDS FOR TEST - SATISFACTORY
7/26/51	FIRED 300 RDS AA PRACTICE - SATISFACTORY

APPLICABLE ORDALTS AND/OR FIELD CHANGES

NUMBER	DATE LISTED	DATE COMP'D	ACCOMPLISHED BY
3008	6/10/51	7/15/51	MINSY

ORDNANCE HISTORY CARD NAVORD FORM 2032 (NEW 5/51)

STOCKED IN CDS

This card will accompany equipment when transferred

16—64497-1

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Figure 13C2.—Ordnance history card (yellow) showing typical entries.

Alterations which materially modify the military characteristics of a ship may be authorized only by Chief of Naval Operations. When so authorized, they are issued by the Bureau of Naval Weapons or such other technical bureau as may have cognizance of the material concerned, as serially numbered NavAlts. Other authorized alterations to ordnance equipment are issued by the Bureau of Naval Weapons as serially numbered OrdAlts. Similarily, ShipAlts are authorized alterations to a ship authorized by the Bureau of Ships. NavAlts, OrdAlts, and ShipAlts contain complete descriptions of the changes to be accomplished. Information is included on the purpose and priority of the alteration; the agency to perform it; the procurement of material; the disposition of discarded material, if any; the weight change, if any; and all necessary plans, diagrams, and specifications.

When your ship receives an OrdAlt, its relevant contents must be entered in the appropriate CSMP card. When the OrdAlt is accomplished, this information is noted in the machinery history, and on a special OrdAlt file card in the weapons department. In addition, BuWeps is notified (on a special form), and the OrdAlt number and date must be entered on the equipment nameplate.

13C6. YARD AND TENDER AVAILABILITY PERIODS

Most commanding officers and most weapons officers take pride in how much work the ship's force can do without formal aid from tender or shipyard. The more maintenance work the ship's force can do (and this includes repairs and alterations as well as upkeep), the better condition the ship and its equipment will be in, the better the crew will know the ship and its equipment, and the lower will be the cost. But there are things that the crew can't do while a ships is in active operation at sea, so periodically every ship has a yard or tender availability period.

As you remember from the first article in this section, the work done by yard or tender is based on work requests made up from the CSMP.

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But before the work requests are made up there's a great deal of other preparation. Yard and tender availabilities aren't an every-Monday-and Thursday affair. Submarines and attack carriers, for example, ordinarily will run about two years between overhauls. This means that every big repair and alteration job MUST be taken care of during the availability period. Shipyards and tenders are busy places and always have plenty of work. Once the availability period is over, the ship can't come back a day or two later because some job wasn't completed or was overlooked in the hubbub.

So a good deal of careful preparation is necessary well in advance. One part of this preparation is inspection by the Navy's highest inspection authority—the Board of Inspection and Survey. This Board conducts acceptance inspections and trials of new ships. It also inspects active ships every three years to determine the state of their maintenance, and it recommends any alterations that may be necessary. And there are other inspections, such as the arrival inspection made by yard engineers whenever your ship arrives at a naval shipyard for overhaul.

The main part of preparation rests on the ship's personnel. It begins with compilation of a work list. The work list is made up of work requests, which in turn are compiled from CSMP cards. The requests include not only work requiring yard or tender assistance, but also jobs that, while within the capabilities of ship's force, requires deactivation of the equipment for more than a day or so. In every case, each request should clearly (though briefly) identify the equipment concerned, state the exact nature of the work required, indicate just what aspects of the job are beyond the skill or tools of ship's personnel, state how urgent the work is, and estimate the time required in man-hours.

The division officer gets the requests, and from them he and the weapons officer compile a worklist. About nine weeks before the ship arrives at the yard or tender, the commanding officer holds a conference of department heads, and at this conference the weapons officer gets his request on the list that will be submitted to the type commander and the yard or tender. The list includes also the items turned up by the inspections made shortly before the availability period is scheduled to begin.

If possible, shipyard estimators and engineers inspect the ship in a prearrival inspection before the ship enters the yard. When the ship arrives at the yard there are conferences between the department heads and the shipyard representatives to determine just which jobs will be done, and how. Or, if the ship has come some distance, the preoverhaul inspection becomes an arrival inspection that is done while the arrival conferences are going on.

The new Standard Navy Maintenance Management System (mentioned in article 13C2) will greatly simplify the process of making up a work list. Most likely the new system will require work requests to be sent in to a central location ashore as soon as they are completed. Punched cards will retain the information for future reference. An up-to-date work list can easily be made at any time using the punched cards. Work requests made at the time of a breakdown or when a job becomes apparent are very accurate and prevent a crash program to make up a work list at the last minute before required for the periodic overhaul.

The yard or tender availability period is a time when a great deal of work can be done that is impractical or inadvisable to try to do (except in emergency) when the ship is fully operational. This doesn't mean getting the tender or yard to do ship's force work. If the weapons officer is one of the many that take justifiable pride in the self-reliance of their crews in such matters, this would not improve your reputation with him. But you can get assistance from yards and tenders on ship's force jobs. Sometimes their maintenance and repair personnel, being specialists, work up special time-saving jigs and tools for specific operations. If you can, it's wise to take advantage of these, along with expert guidance from yard or tender specialists, during the availability period.

In naval shipyards the formal line of contact between the yard and a ship is through the engineer officer of the ship and the ship superintendent assigned by the yard to your ship during the availability period. The unit in the yard that handles all electronics jobs is Shop 67. (All naval shipyards have parallel organization and nomenclature of operating subdivisions.) The weapons department's line of contact to this shop is by way of the weapons officer, the engineer officer, the ship superintendent, and the shopmaster (of Shop 67).

Tenders are also organized into departments, but the setup is different. The weapons officer's contact would be the ordnance repair officer in the tender, and the division heads on the ship have direct contact with the divisions on the tender that they have business with (such as the machine shop, optical shop, fire control shop, and so on).

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D. Training

13D1. GENERAL ASPECTS OF TRAINING

In any department on board ship no single factor more affects performance than the efficiency and spirit of its personnel. It is not even necessary in this generalization to hedge it with the qualification "other things being equal." You can probably quote any number of illustrations of this from your orientation course.

The efficiency and spirit of the personnel in any department depend heavily upon training. Training starts at the lowest level, goes right up to the highest, and is never finished. It must at all levels be a continuous, progressive, and challenging process, designed around realistic problems and situations, and intelligently handled to create and maintain interest and enthusiasm.

All this applies as much, if not more, to the weapons department as to any other. One of the duties of the weapons officer is the supervision and direction of the employment of ordnance equipment. It is the junior officer's duty to implement this program by proper training of personnel. There are several requisites for an effective training program. The junior officer must be completely familiar with the ordnance equipment for which he is responsible. This includes not only operating procedures, but theory and design characteristics as well. He must ensure that petty officers and other key personnel, who will conduct instruction on station, are themselves competent and well informed. The junior officer must carefully appraise his men and assign them stations in accordance with their capabilities, both mental and physical. Some information can be obtained from the service record of each man, which is available in the ship's office. The division officer should supplement this with a division notebook, which should contain detailed data on each man in the division, as well as a copy of the division watch, quarter, and station bill.

Finally, the junior officer cannot neglect his own training. He must apply himself continually and learn not only his job but the jobs of those who are immediately senior to him. Current policy is to keep a junior officer aboard a destroyer for three years, during which time he will become department head for approximately the last 18 months of his tour. When the time comes for "fleeting up" to department head, he must be ready.

13D2. THE NAVY'S TRAINING PROGRAMS

The Navy has not only one training program, but many. One of them is concerned with your studying this book right now. To the division officer aboard ship, the important programs can be considered in three categories:

1. Team training programs for the ship's personnel.
2. Individual training programs for enlisted personnel.
3. Individual training programs for commissioned officers.

Team training programs are those in which groups participate for group training. There are more varieties of team training programs than can ever be summarized here. They range all the way from fleet maneuvers including thousands of men and scores of ships and aircraft, to loading drill practice in which only three or four men are participating.

Individual training programs may actually involve group study and instruction, but are concerned with teaching the individual.

The Navy's training programs are not confined to schools—even special Navy schools—though the Navy does make use of schools. To get a quick picture of the Navy's training programs, let's trace briefly through the training of an enlisted man, then that of an officer. In reading both of these discussions, bear in mind that we are here particularly concerned with what you may expect to encounter aboard ship in the weapons department. Don't consider these brief summaries as a complete exposition of the whole picture.

13D3. CAREER OF AN ENLISTED MAN

Training of an enlisted man starts soon after induction. When he's inducted, he's a Seaman Recruit (SR). This is the bottom of the ladder. He goes to boot camp. Boot camp, more formally known as recruit training school, is actually a Navy elementary school, where the recruit learns the basics of Navy life. In boot camp, the SR is not only trained, but tested and screened. He takes intelligence tests, test of

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ability to use numbers, mechanical and other aptitude tests, interviews, etc. Then he's evaluated and screened on the basis of these tests, and this to a considerable degree determines his career in the Navy. For example, the scores on his tests determine whether he is eligible to try for certain ratings. Electronics Technician and Fire Control Technician strikers, to specify two such ratings, must have passed their tests with relatively high minimum scores in general intelligence, ability to handle numbers, and mechanical aptitude.

It's at this stage also (if it hasn't been done before) that a recruit is shunted into the particular branch he's interested in and qualified for, such as seaman apprenticeship, construction apprenticeship, or medical apprenticeship, to mention a few. As he rises in any of these fields, he becomes more specialized. Recruits with especially favorable test scores and backgrounds may at this stage be "designated" for even greater specialization. Thus a recruit with experience in precision machinery or electronics, and good intelligence and mechanical aptitude scores may go direct from boot camp to specialized "class A" school from which he graduates as a "designated striker" to be assigned to the weapons department as soon as he reports on board ship.

More frequently, however, the recruit when he emerges from boot camp has been advanced to apprentice (Seaman Apprentice or SA, if he's been assigned in that branch) and is sent to a ship, where he becomes part of the deck force. (On a destroyer, this would be the first or second division.) After several weeks or months under the observant eye of his division officer and the petty officers immediately over him, they can fairly accurately appraise his career potentialities, and he can be transferred from the deck force to some group in which his talents and interests can be best employed. After 6 months as an SA he can take a written test, which is given by the ship, to become an SN, assuming he meets all other requirements. He can become a designated striker as an SA or SN provided he meets all the requirements.

To get the rate he's striking for, the candidate for advancement to third class petty officer must:

1. demonstrate that he can actually perform the practical requirements of the rate as evidenced by the Record of Practical Factors, NavPers 760.

2. successfully complete the required military and professional correspondence courses. If required, the striker must also have attended a service school. (More about this later.)

3. pass a written servicewide examination on the technical aspects of the rate and rating he's striking for and on the military requirements for the rate.

4. be recommended for promotion by the ship's commanding officer. (In effect, this is the equivalent of saying that he must be considered qualified by his supervising petty officers (PO's) and have been recommended by his division officer.)

5. have been in grade and in the Navy the required minimum time.

BuPers directives promulgate all these requirements in detail. The list above is only an abbreviated review.

The striker's chances for advancement depend on his examination (item 3 above) score and other factors such as length of service, proficiency marks, and awards, which all together determine his score total. If he has a passing mark this can qualify him for advancement to third-class petty officer for the particular specialty (rating) he's striking for, but he isn't automatically moved up to this rate. Instead, the names of all those who took the examination are arranged in the order of their standing, and those highest in the list are advanced until the Navy's requirements for this particular rate are satisfied.

The advancement of petty officers continues step by step (no skips permitted) in this general pattern through all the grades up to the highest (Master Chief). It is worth while for the division officer to remember that many an able man can fully qualify for advancement but not actually be advanced, simply because in his rating there are fewer available billets than qualified candidates for advancement.

For enlisted personnel, the top of the ladder may be Master Chief, or able men may become warrant officers (in general, these are highly qualified technical experts) or commissioned officers (colloquially called "mustangs").

13D4. CAREER OF AN OFFICER

Let's now glance briefly at how an officer rises in the ranks. In contrast to the picture in the preceding article, where in a sense you're outside of the frame of reference, you're right in the middle of this one.

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For an officer, the bottom of the ladder is the rank of ensign. Some attain this rank from (as the preceding article pointed out) enlisted or warrant status, by way of OCS (Officer Candidate School). Others are Naval Academy graduates, or NROTC or other college officer training graduates.

We won't go here into the details of the complex machinery of officer promotion, but you probably know already that an officer is selected (i.e., declared eligible) for promotion before actually being promoted. To ensure himself of actual promotion, a selected officer must be prepared for it. Aside from the obvious matter of knowing his job and doing it so that it will do him credit, he must also train himself systematically, so that he will be ready for promotion when it looms ahead. Here are some aspects of this training preparation.

1. CORRESPONDENCE COURSES. United States Navy, Armed Forces Institute (USAFI), or other correspondence courses are recommended for all officers to help prepare themselves for advancement and to broaden their knowledge. This is not a requirement for advancement, however it may influence the selection board (LT and above) favorably if an officer has completed some correspondence courses. Both the fleet and the Bureau of Naval Personnel have correspondence courses available. Fleet administered courses prepare the student for specific officer assignments, such as officer of the deck, weapons officer, and communications officer. BuPers administered courses take up technical subject areas such as military justice, naval engineering, damage control, and the like. It's best for an officer to take courses voluntarily, but his commanding officer may require him to take certain courses —for example, if the ship hasn't enough navigators, you may be required to take the navigator course so that you can qualify without delay and alleviate the shortage. Since in normal practice an officer can take only one course at a time, and completion of a course may take a year or more, it's clear that a career-conscious officer must plan far ahead—even if he's an ensign and doesn't have his name go before a selection board for promotion. BuPers publishes lists of Navy correspondence courses. USAFI publishes lists of correspondence courses with subjects at both high school and college level, and a list of correspondence courses available from civilian colleges and universities cooperating with USAFI.

2. POSTGRADUATE COURSES. The Navy has arrangements for officers with some experience to take postgraduate training on college campuses (these may lead to a degree) or at the Navy postgraduate school at Monterey, California.

3. OTHER NAVY SCHOOLS. The Navy has other officer training courses on specific subjects such as damage control or defense against nuclear, bacteriological, or chemical (NBC) attack. These are generally much briefer than the first two types of courses mentioned above, and are offered by BuPers.

The next section in this chapter will indicate the self-training and orientation that the junior officer should consider himself responsible for when he first reports aboard his ship.

13D5. SHIPBOARD TRAINING

Now let's see how the Navy's training programs fit into Navy career patterns.

Both shipboard training and training in Navy schools have individual training and team training aspects.

Individual training aboard ship is concerned with such activities as taking correspondence courses, and sometimes even (especially aboard larger ships) with organization of formal classes. Usually, however, individual training in which an instructor teaches students occurs in such situations as where an FT1 or FTC teaches a couple of strikers how to tear down an instrument servomechanism, or to troubleshoot a malfunctioning electronic circuit, etc. In addition to such job training, both enlisted and officer personnel can take broader courses offered by USAFI; for example, many men who did not finish high school before they joined the Navy have done so through USAFI.

Navy schools are also a form of individual training. School attendance is required for advancement in rate in certain ratings. In highly technical ratings, such as FT and ET, it is almost a must. Schools are always desirable and helpful for advancement in rate. A man who graduates from a Navy school is valuable to the Navy and at the same time helps himself get ahead.

Team training on board ship may be either operational or in maintenance work. (The latter would include such work as boresighting or other battery alignment operations which require a team of men working together.) Operational

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training can occur either aboard ship or ashore, and may involve a team of almost any size. Aboard ship, operational team training includes such activities as GQ drill, loading drill (on gun mounts), drills in various bills, and CIC drill. Operational drills have enormous potential training value, but for the value to be realized the leaders of the drill (and this quite often means the junior division officer or the division officer) must function imaginatively, but with a lively sense of the businesslike purpose of the drill. Other operational training includes gunnery exercises, multiship exercises (such as ASW drill), and the like. One aspect or another of team training will, in fact, dominate your duty hours aboard ship,—or if it doesn't, it should. It is consequently the aspect of your work as division officer that should get maximum attention, and certainly the maximum amount of constructive thought.

Fortunately, team training can go on even when the crew is not on board ship. All ships must periodically go to a tender or naval shipyard for overhaul and heavy maintenance work. Yard work generally means several weeks in which the ship, even if not actually in drydock, cannot be operated because its machinery and armament are partly or completely disabled, and there is no ammunition or fuel aboard. During this period, even if some of the crew is on leave, some can be sent to fleet training schools which specialize in specific weapons such as the 3"/50. Other fleet training activities ashore give quick, intensive short courses (aboard "school ships" temporarily assigned for this purpose, or in shore facilities) in UB plot operations, CIC, spotting, etc.

Following every yard period comes a period of underway "refresher" training (generally for 5 to 6 weeks) in which the crew (many of whom have been replaced during the yard period) goes through a complete series of training sessions at sea, while at the same time the ship is put through its paces to check its overhaul. This culminates in the Operational Readiness Inspection (ORI) in which officers from the highest echelons of the Fleet check the ship and its crew in every aspect of operational preparation. However, though we have called the ORI a "culmination" of underway refresher training, this by no means implies that the training program can come to a standstill; it is in fact only the beginning of continuous, endless process.

You as a junior division officer or division officer will have your area of responsibility in every training program that affects the weapons department—and few do not affect it.

13D6. WEAPONS EXERCISES

One of the most important aspects of team training is the weapons exercise. The most important objective in weapons exercises is to train personnel in the most effective use of the ship's armament. Another important objective is the development of new doctrines, techniques, and procedures to keep pace with new targets and new equipment. Hence the conditions under which they are held are made as realistic as possible, to eliminate artificialities which might lead to false conclusions.

Publications promulgated by CNO prescribe the weapons exercises now used in the fleet. Separate publications prescribe the training exercises, procedures, and reports required, including outlines of the specific tactical situations which precede the firing. These publications are confidential, and are in the custody of the Registered Publications System (RPS) Custodian. They may be signed for and drawn for study. Frequent reference to the weapons department files will keep the officer posted concerning past weapons performance as well as current doctrines and procedures.

Just as important as the firing exercise operations themselves are the reports that must be made of the operations, and the analysis of the reports. Too frequently reports of weapons exercises lose their significance and serve merely to represent additional paper work to the junior officer. Remember that it is necessary to make an accurate appraisal of the effectiveness of the ship's armament, and that to do so requires careful, detailed analysis of accurately compiled reports.

Sufficient data must be taken during the exercise to permit postfiring analysis. It must be carefully assembled and even more carefully checked. If the report indicates an ineffective battery, every last detail must be scrutinized to ascertain the cause—which must then be corrected.

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E. Effective Naval Leadership

13E1. INTRODUCTION

Naval leadership means the art of accomplishing the Navy's mission through people. Effective leadership is based on personal example, good management practices, and moral responsibility. The United States Navy has long been distinguished for the high quality of its officers and men. The following discussion is designed to point out the requisites of being a leader, improving on leadership capabilities, and exercising leadership qualities.

13E2. THE LEADER

Few people are born leaders. The majority of leaders (in civilian life as well as in the military) have utilized their innate abilities to best advantage, learned their jobs thoroughly, and applied common sense to the task at hand. These men have thus earned for themselves the respect, admiration, and loyalty of their superiors and subordinates alike—they have become leaders.

The best military leaders are characterized by patriotism, valor, integrity, ability, initiative, imagination, judgment, loyalty, dependability, tact, self-control, and, above all, a "can-do" attitude to accomplish a mission despite the obstacles.

Don't let this formidable list daunt you. Leadership is a prerequisite to success, and fortunately most men willingly accept direction from their seniors.

13E3. LEADERSHIP DURING OFFICER TRAINING

The Navy cannot produce all-around leaders in the various officer candidate schools (the U.S. Naval Academy, NROTC Schools, OCS, ROC, etc.). But it can give them the best leadership education possible at the academic level. Beyond this, you can become a good and successful leader only from practice and training aboard your ship or station.

As college students in the NROTC program or candidates in OCS, you should be developing your leadership potential. If you aren't, now is the time to start working at it. Leadership is not bestowed upon anyone automatically upon graduation or through being sworn in as a commissioned officer. Leadership must be learned through exercise.

13E4. LEADERSHIP ON BOARD SHIP

Leadership has been defined many ways. One popular version is: "The ability to have others do what you want them to do because they want to do it."

The naval weapons concept that you have studied doesn't eliminate the individual; paradoxically it increases the responsibilities and capabilities required of the operating personnel. The effectiveness of any weapon system depends on the knowledge and operation of the component parts of the system by the operating personnel. As a result, the junior officer has to be a combination technician, tactician, leader, and follower.

Why is the "can do" attitude so important? Because it's results, not technical potentials, that count. The command that utilizes its equipment to maximum effectiveness will defeat a more technically advanced adversary whose personnel are not as proficient employing its weapons to maximum effectiveness.

We can never afford to blame our technical and tactical ineptness on equipment. Nor can we rationalize that better equipment will make up for our shortcomings. Former Chief of Naval Operations, Admiral Arleigh Burke, emphasized on many occasions that "the fleet must always do the best with what it has."

13E5. LEADERSHIP FOR THE JUNIOR OFFICER

As a junior officer you may be assigned tasks below your potential. This is a normal evolution—minor responsibilities diligently and efficiently performed lead to more challenging and interesting assignments. It is commendable and essential to set a high goal to strive for, but the higher the goal the more devoted and patient you must be. There is always room for one more industrious, conscientious, imaginative officer in any wardroom. Learn your own job regardless what it may be, prepare yourself for additional responsibilities and it won't be long before you will be fleeted up as a department head.

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The standards of the Navy are set by your superiors, but the successful attainment of those standards depends upon the cooperation of the junior officer in insuring that those standards are understood and complied with.

As a junior division officer in the weapons department—or any department for that matter—you will find that you are expected to learn on the job and perform tasks that you were not adequately taught. Junior officers' ability to learn on the job affects the operations of a department in a large combat ship—but it can make or break the entire command the size of a destroyer.

The Navy shows great tolerance and forebearance to the junior officer who conscientiously and industriously carries out his duties, who isn't afraid to dig for the information he needs, and who in every way evidences a sincere desire to do his best as a naval officer. Every ship's complement is composed of such numbers, ranks and ratings of officers and men as are required to operate the ship most effectively in war and in peace. There is never room for deadwood.

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APPENDIX A

GLOSSARIES

Introduction. This appendix is in two parts. The first part is a general glossary which lists in alphabetical order all terms and abbreviations for which this text undertakes to provide definitions or explanations, plus a few others. The second part is an alphabetical listing of all surface and AA gun fire control symbols, each with a brief explanation, in common use at the present time.

The general glossary is intended as a convenience to the student in home study and other situations where standard authoritative Navy reference sources are not readily available. It is not intended to supplant or supersede authoritative sources. Nor should it be used for general reference; the definitions of most of the terms and symbols included in it, regardless of what they denote in general use or in other technical areas, are intended to apply primarily to Navy usage.

To avoid inconvenient length, the glossary entries are mostly brief, and do not usually go into details regarding derivations, shades of meaning, limits of application, etc. For further information on any entry, or for information on any term not in the glossary, the student should look it up in the index to determine if there is further discussion in the text, and should then go to other reference sources if necessary.

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Part 1: General Glossary

AA: Antiaircraft.

AAC: Antiaircraft common (projectile).

Aberrations: Distortions in an optical system.

AC Device: In mines, an anticountermining device that prevents the mine from detonating because of a nearby explosion.

ACP: (See NWP.)

Acquisition: The process of accepting a designation, acquiring the target, and the initiation of target tracking.

ACTH: (See Arbitrary Ballistic Correction.)

Actuation Counter: A device used to complete the electrical circuit to the mine detonator after a preset number of firing system actuations.

ADF: Auxiliary detonating fuse.

Advance Range: Present range combined with the corrections and predictions necessary to compensate for own ship and target motion during the time of flight, plug ballistic corrections and spots.

A-End: The variable-output pump in a hydraulic speed gear.

AF: Audio frequency, especially with regard to sonar signal fed to loudspeakers or headphones.

Afterbody: The part of a torpedo between the midship section and the tail. Usually contains propulsion and guidance equipment.

Aiming: The process of establishing target position in bearing and elevation.

A. Aim is classified as to Type by the instrument employed:
   1. Radar Aim describes determination of target bearing and elevation by radar.
      a. Partial Radar Aim describes determination of bearing by radar and determination of elevation by stabilizing equipment.
   2. Optical Aim describes determination of target bearing and elevation by optical instruments.
      a. Partial Optical Aim describes determination of target bearing by optical instrument and elevation by means of stabilizing equipment.
   3. Generated Aim describes the generation of target bearing and elevation, and corrections thereto for deck inclination, by means of a computer and stabilizing equipment.

B. Aim is classified as to Method by the manner in which the aiming system is operated.
   1. Continuous Aim describes continuous measurement of target position in bearing and elevation.
      a. Continuous Automatic Aim describes automatic continuous aiming instrument.
      b. Continuous Aided Aim describes continuous aiming with the aiming instrument positioned by signals received from the computer and with the resulting position corrected by the operators.
      c. Continuous Manual Aim describes continuous aiming with the aiming instrument positioned by hand, using either direct manual drive or local power.
   2. Intermittent Aim describes periodic measurement of target position in one element and continuous measurement in the other.
      a. Selected Elevation describes determination of target position continuously in bearing and intermittently in elevation.
      b. Selected Train describes determination of target position continuously in elevation and intermittently in train.

Airborne Early Warning (AEW): AA search by craft other than own ship.

Airburst:
1. An explosion of a bomb or projectile above the surface, as distinguished from an explosion on contact with the surface or after penetration.
2. The explosion of a nuclear weapon in the air at a height greater than the maximum radius of the fireball.

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Air Flask Section: In an air-steam torpedo, the midship section.

Air-Steam Torpedo: A torpedo propelled by a turbine engine driven by a mixture of air and steam.

Alternating Current (or voltage) (a-c): Current or voltage that periodically reverses polarity in a circuit. Commonly, if the value is plotted on a graph against time, the result will be a more or less smooth sine wave; this is the characteristic output waveform of transformers and generators. A-c supplies on ships are generally either at 60 cps or 400 cps.

Altitude: The vertical component of slant range. (Since this definition disregards the curvature of the earth, it should not be applied beyond the limits of present gun fire control systems.)

Amatol: A mixture of ammonium nitrate and TNT.

Ammunition: A contrivance charged with explosives, propellants, pyrotechnics, initiating composition, or nuclear, biological, or chemical material for use in connection with defense or offense, including demolitions.

Ammunition Details: Components of a round of ammunition.

Amplidyne (Generator): A highly variable-output d-c generator identified with this trade name.

Amplidyne System: A system in which a small signal regulates output of a d-c amplidyne generator that feeds a servo motor.

Amplitude: Distance through which a particle is displaced in vibration; a measure of amount of vibration.

AN/: Army-Air Force-Navy designation.

Analog Computer: A computer which solves a certain type of problem by using electrical or mechanical analogs whose end output represents the solution. Cf. Digital computer.

Angle of Climb or Dive: The vertical angle between the horizontal and the direction of motion of the target measured in degrees at the target.

Angle of Incidence: Angle between an incident light ray and the normal at an optical surface.

Angle of Reflection: Angle between normal and reflected ray.

Annunciator: An alerting device used to indicate to personnel that target designations are pending.

Antisubmarine Barrier: The line formed by a series of static devices or mobile units arranged for the purpose of detecting, denying passage to, or destroying hostile submarines.

Antisubmarine Warfare: Operations conducted with the intention of denying the enemy the effective use of his submarines.

Antisubmarine Warfare Forces: Forces organized primarily for antisubmarine action. May be comprised of surface ships, aircraft, submarines, or any combination of these and their supporting systems.

Apparent Mean Dispersion of a Salvo in Range (or deflection): The arithmetical average of the dispersion in range (or deflection) of the several shots of the salvo, excluding wild shots.

Apparent Wind: Wind apparent at the observing station; the resultant of the true wind and the motion of the observing station.

Arbitrary Ballistic Correction: An empirical correction in range or deflection to compensate for all indeterminate errors in the fire control problem. It is obtained from an analysis of previous firings. This is commonly referred to as ACTH (arbitrary correction to hit).

Area Fire: Support gunfire delivered in a prescribed area. Usually used in neutralization support fire.

Armament: (See Ordnance.)

Armature Reaction: Magnetic field produced by induced armature current in a d-c generator.

Arming: As applied to explosives, the changing from a safe condition to a state of readiness for initiation.

Arming Wire: A wire harness used to initiate arming of a weapon.

A/R Scope: A type of fire control radar display.

A/S: Antisubmarine (adjective).

Asroc: AntiSubmarine ROCket. A surface ship-launched, rocket-propelled, nuclear depth charge or homing torpedo.

Astor: AntiSubmarine TORpedo. A submarine-launched, long-range, high-speed, wire-guided, deep-diving, wakeless torpedo capable of carrying a nuclear warhead for use in antisubmarine and antisurface ship operations.

ASW: Antisubmarine warfare.

ATP: (See NWP.)

Attack Director: Electromechanical analog computer used to solve underwater fire control problem.

Attrition Mining: Mining primarily for the purpose of destroying enemy ships.

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Audio: Audible signal, or electrical signal that eventually is used in production of audible signal.

Autofrettage: A method for prestressing gun barrels by radial expansion.

Auto(matic) Control: Control of a gun mount entirely and directly through remote signals from a fire control system.

Automatic (Gun): Case gun in which some of the propellant's energy is used to open the breech, eject the empty case, and load the next round.

Auxiliary (Explosive or Propellant): Substance used in intermediate stages in an explosive train.

Axial-Piston Pump: A pump that consists of a group of cylinders in a barrel, arranged parallel to the axis of the barrel's rotation.

Axis of Bore: The extension of the central axis of the gun bore. It is tangent, at the muzzle, to the trajectory of a projectile fired from the gun.

AXP: (See NWP.)

Azimuth: The horizontal angle in mils measured from grid north to the OT (observer-target) line.

Azimuth Search Sonar: Sonar system that radiates transmitted pulse in all directions and scans spirally in 360° of azimuth.

Bag Ammunition: Gun ammunition with propellant in fabric bags and with separate projectiles and primers.

Ballistic Corrections: Corrections in range and/or deflection to compensate for known or predicted errors, for drift, for wind, and for all variations from standard range-table conditions.

Ballistic Cross Wind: The horizontal component of the ballistic wind at right angles to the target bearing.

Ballistic Density: The single air density, determined by computation, which would have the same range effect on the projectile as the actual densities throughout the trajectory.

Ballistic Missile: A guided missile designed to follow for a substantial part of its flight a ballistic (free or unsteered) trajectory.

Ballistic Range Wind: The horizontal component of the ballistic wind parallel to the target bearing.

Ballistics: The science that deals with the motion, behavior, appearance or modification of missiles or other vehicles acted upon by propellants, wind, gravity, temperature or any other modifying substances, conditions or force.

Ballistic Trajectory: The trajectory traced after the propulsive force is terminated and the body is acted upon only by gravity and aerodynamic drag.

Ballistic Wind: The effective wind, determined by computation, of such force and direction that its action on the projectile during the time of flight will be the same as the combined actions produced by the various true winds acting in the strata through which the projectile will pass as it moves along the trajectory.

Barrage: Barrier of fire executed on predetermined firing data. The initial shots are placed across the probable path of the target.

A. Barrages are classified as to Method by the manner in which position of the bursts is varied.
   1. Line-of-Sight Barrage is a barrage using fixed fuze setting and varying sight settings, with each shot so directed that bursts will occur in the instantaneous line of sight to the target.
   2. Fixed-Zone Barrage is a barrage fired with fixed sight settings. Once the target has passed through the zone of fire, a second zone may be selected and a new barrage fired.
   3. Creeping-Zone Barrage is a barrage in which the fuze settings are varied in such a way as to advance along the track slower than the actual target advance.

Barrel (Gun): Part of gun structure that contains the bore.

Base Length (of Rangefinder): Distance between windows.

Base Ring: Base section of rotating structure of gun or rocket mount. Also called "deep section ring" or "lower carriage."

Base Surge: A cloud which rolls out from the bottom of the column produced by a subsurface burst of a nuclear weapon. For underwater bursts the surge is, in effect, a cloud of liquid droplets which has the property of flowing almost as if it were a homogeneous fluid. For subsurface land bursts the surge is made up of small solid particles but still behaves like a fluid.

Basic Mechanisms: Elementary components of machinery, including various basic machines.

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Bathythermograph: A recording thermometer that shows water temperature at various depths.

Batten Board: Flat screen with target markings. Some times used in boresighting.

Battery: All guns, torpedo tubes, searchlights, or missile launchers of the same size or caliber are used for the same purpose, either installed in one ship or otherwise operating as an entity.

Battery Alignment: Alignment of weapons and fire control equipment to a common system of reference lines and planes under specified conditions.

Battery Compartment: In an electric torpedo, the midship section.

Battery Control: The direction of the employment of all the mounts or turrets of a similar caliber or purpose in a vessel. It is concerned with the disposition of the mounts or turrets with respect to the fire control stations of the battery, the interior communications plan to be used, the designation and acquisition of targets by the battery or group, and the standard procedures to be employed. The Battery Control Officer is assisted by Group and Sector Control Officers, and by CIC Weapons Liaison Officers.

1. Battery Control is classified as to Type by the manner in which the command of the battery is exercised.
   a. Collective Battery Control is that type of battery control in which the direction of the employment of the battery is centralized.
      (1) Divided Battery Control is that form of dispersed control wherein a battery with two directors is divided into forward and after batteries for command purposes. This form of control is associated with centerline, single purpose batteries.
      (2) Sector Battery Control is that form of dispersed control in which a battery with multiple directors is divided into sectors for control purposes.
2. Battery Control classified as to Method prescribes the grouping of the mounts or turrets with fire control stations, command communications channels between fire control stations, and procedures for designation and acquisition. For a particular vessel the groupings are prescribed in the battle bill.

Battery Position: Recoiling parts of gun in position for gun to fire.

Battle Announcing System: A system of microphones, amplifiers, and loudspeakers used for internal communication aboard ship.

Battle Bill: A table listing stations to be manned and personnel required under battle conditions aboard ship.

Battle Control Stations: Primary key points of ship's battle organization.

Battle Telephone: Sound-powered telephone.

Bazooka: A small infantry-launched rocket originally designed as an antitank weapon.

BDF: Base detonating fuze.

Beach Defense Mine: Bottom mine laid in shallow water to destroy landing craft.

Beacon:

1. A self-propelled noisemaker ejected by a submarine to distract A/S attack.
2. A radar signal transmitter used to establish a reference point or for other purposes. (Also called Racon.)

Beam Rider: A missile guided by a radar or radio beam.

Bearing Rate: Rate of change of target bearing from own ship caused by the relative motion of own ship and target. It may be expressed in knots (linear measure) or in degrees per minute (angular measure).

Bell (Gun): Thick part of gun muzzle (not on all guns).

Bench Mark: In battery alignment, a reference point on own ship structure used for aligning battery directors.

B-End: The hydraulic motor in a hydraulic speed gear.

Bill: A written directive that prescribes a procedure for performing some operation, or dealing with some specific situation. It lists what is to be done, material needed, and who does it.

Billet: A specific duty or station assignment to which an individual may be named, or a combination of such assignments to which a single individual is named.

Billet Number: A code designating a crewman's division, section, and precedence.

Biological Weapon: An item of materiel which projects, disperses or disseminates a biological agent including arthropod vectors.

BL: Blind-loaded. Equivalent to Sand-loaded or Plaster-loaded.

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Black Powder: An explosive mixture (used usually as an auxiliary) made up of carbon, surfur, and saltpeter.

Blank Ammunition: Gun ammunition lacking projectiles.

Blasting Cap: Demolition charge initiating device.

Blind Time: Time lapse from instant of firing of an A/S weapon till it reaches predicted position of submarine target.

Blip: Element of radar or sonar video presentation. Also called "pip."

Blipology: Interpretation of cathode-ray tube displays.

Blowback: Escape, to the rear and under pressure, of gases formed during the firing of the gun. Blowback may be caused by a defective breech mechanism, a ruptured cartridge case, or a faulty primer.

Bomb: A missile containing explosive or chemical filling generally dropped from an aircraft.

Booster:

1. A unit in an explosive train which causes detonation of the main charge.
2. An auxiliary or initial propulsion system which provides initial thrust.

Boresafe (Fuze): A fuze designed to arm only after the projectile passes the gun muzzle.

Boresighting: Adjusting sights to be parallel with gun bore axis or to make their lines of sight intersect gun bore axis at some specified range.

Bottom Mine: A mine designed to be laid on sea bottom. Formerly called ground mine.

Bourrelet: Annular part of a projectile forward of the rotating band.

Bracketing: A method of adjusting fire in which a bracket is established by obtaining an over and a short along the spotting line, and then successively splitting the bracket in half until a target hit or desired bracket is obtained.

Breechblock: Gun mechanism element that blocks chamber when gun is fired. Also called "plug."

Brisance: Rapidity with which an explosive develops its maximum pressure.

Brush: Contact used with slip rings and commutators.

B-Scope: A type of fire control radar display.

BT: Abbreviation for bathythermograph.

Built-up (Gun): A type of prestressed gun barrel.

Burnout: The point in time or in the missile trajectory when combustion of fuels in the rocket engine is terminated by other than programmed cutoff.

Burster: Bursting charge or explosive load in a projectile, mine, torpedo, etc. Final unit in an explosive train.

BuShips Technical Manual: Bureau of Ships Manual. Technical compilation on shipboard equipment, some of it related to ordnance.

Caliber: Nominal diameter of projectile or mating gun bore, or diameter of rocket head.

Call Fire: Fire delivered on a specific target in response to a request from the supported unit.

Call For Fire: A request for fire containing data necessary for obtaining the required fire on a target.

CAP: Combat Air Patrol.

Carbamite: A stabilizer used in SPCG.

Carrier Striking Force: A naval task force composed of aircraft carriers and supporting combatant ships capable of conducting strike operations.

Cartridge Case: (See Case Ammunition.)

Case Ammunition: Gun ammunition with propelling charge and related components in a metal or plastic cartridge case.

Cavitation: Formation of partial vacuum on certain parts of fast-rotating ship screws; this causes inefficiency and considerable acoustic disturbance.

CD Mechanism: In mines, a clock delay device to delay arming for a period after planting.

Cellulose Nitrate: (See Pyrocotton.)

Center of Burst: A point about which the bursts of projectiles fired under like conditions are evenly distributed.

Central Amplifier System: A type of battle announcing system.

Centrifugal Force: In a rotating object, radial thrust away from center of rotation caused by inertia.

Chamber (Gun): That part of the gun in which the propelling charge is located when the gun is ready to fire.

Chase (Gun): (See Gun Chase.)

Chemical Agents: Substances used in munitions for signaling, screening, asphyxiation, or chemical attack. The three main varieties of chemical agent are war gases, smokes, and incendiaries.

Chemical Torpedo: A type of air-stream torpedo that uses hydrogen peroxide to support fuel combustion.

Chronograph: Any of several devices used to measure and record velocity of a gun projectile after it leaves the muzzle.

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CIC: (See Combat Information Center.)

Closed-Circuit Television: (also Closed-Loop Television) A television installation in which the signal is transmitted by wire to a limited number of receivers.

Closed-Loop Servo: A servosystem in which a servomotor is employed to amplify a comparatively weak signal. It is composed of an error detecting device, an error signal amplifier, and a motor. Input signals and the response of the motor are compared by the error detecting device. The resultant error is amplified and drives the motor. The motor rotates in such a direction as to cancel the error signal.

Close Support Area: Area between friendly front lines ashore and the near limits of zones of responsibility.

Close Support Fire: Fire placed on enemy troops, weapons, or positions which, because of their proximity, present the most immediate and serious threat to the supported unit.

Closure Mining: Mining primarily for the purpose of preventing passage of enemy ships.

Cock: A plug type valve seated in a pipe. A petcock is generally used to open or close a drain or other type of exhaust opening in a system.

Collimating Lens: A lens used to produce parallel light rays.

COM: Common (projectile).

Combat Information Center: The agency in a ship or aircraft manned and equipped to collect, display, evaluate, and disseminate tactical information for the use of the flag officer (if embarked), commanding officer and certain control agencies. Certain control, assistance and coordination functions may be delegated by command to the Combat Information Center.

Combustion Flask (Torpedo): Compartment in which fuel-air mixture burns.

Commutator: Rotating contact system consisting of a ring-like arrangement of insulated metal bars, or other groups of discrete contacts which are touched sequentially by a brush as a rotor turns.

Compensator Wedges: Thin optical prisms used in optical rangefinder.

Complete Round: All ammunition details required to fire one shot.

Compression Waves: (See Longitudinal Waves.)

Concentration Area: A limited area on which a volume of gunfire is placed within a limited time.

Conditions of Loading: In interior ballistics, the powder used, the weight of charge, the density of loading, the volume and shape of the powder chamber, and projectile weight.

Condition Watch: Aboard ship, a personnel disposition based on degree of readiness.

Conical Scan: In radar, a type of antenna beam scan used for target tracking. The scanning is characterized by having a fixed tilt angle. The axis of the r-f beam generates a cone whose vertex angle is usually from five to ten degrees.

Conservation of Energy, Doctrine of: Except for nuclear reactions, the quantity of energy in the universe remains the same, but may be converted to different forms.

Constriction: Narrowed part of gun bore.

Contact: In AA or A/S search, a detected potential or actual target.

Contact Mine: Mine that will explode when target touches the mine or one of its sensitive components such as an antenna. Contact firing mechanisms may be mechanical, galvanic, or electrochemical.

Control: Authority, less than full command exercised over the armament or a portion thereof.

Control Indicator: (See Sonar Control Indicator.)

Controlled Mine: Mine controlled from a station ashore.

Control Units: (See Weapon System.)

Conventional Weapons: Nonnuclear weapons. Excludes all biological weapons, and generally excludes chemical weapons except for existing smoke and incendiary agents, and agents of the riot-control type.

Convergent Lens: A lens that causes parallel light rays entering it to converge.

Convoy: A formation of merchantmen (usually under naval protection).

Cool Propellant: Propellant that burns at relatively low temperature.

Coordinate Converter: An electromechanical instrument used to compute bearing and range from north-south east-west position. It can also compute the north-south east-west position from director train and range information.

Copper Fouling: Metal residue deposited in gun bore by erosion from rotating bands.

Cordite N: (See SPCG.)

COSAL: COordinated Shipboard Allowance List. An allowance list of consumable parts required to support a ship's on-board equipment. It is determined by a physical

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inventory of the on-board equipment on an INDIVIDUAL ship basis.

Counterbattery Fire: Support fire directed against enemy weapon emplacements for the purpose of silencing them.

Countermeasures: That form of military science which by the employment of devices and/or techniques has as its objective the impairment of the operational effectiveness of enemy activity.

Countermining: The detonation of mines by nearby explosions, either accidental or deliberate.

Counterrecoil: Movement of recoiling gun parts toward battery position. This is accomplished by a "counterrecoil mechanism" or "recuperator."

Counterrotation: Rotation in opposite directions.

cps: Cycles per second.

Creep: Forward thrust on fuze parts caused by gradual slowing of projectile in flight.

Critical Angle: At angles of incidence greater than the critical angle, all incident light is reflected back into glass. (This property is called "total internal reflection.") The value of the critical angle depends on the refractive index of the glass.

Crosshairs (or Crosswires): Reticle marks consisting of a pair of mutually perpendicular lines (horizontal and vertical).

Crosslevel Angle: Inclination of the battery reference plane with the horizontal, usually measured in a plane perpendicular to the plane in which level is measured. The latter plane may be either the vertical or a plane perpendicular to the reference plane, depending on the design of the control equipment.

CRT: Cathode-ray tube.

CS Mechanism: In mines, a clockstarter device that starts or stops the timing mechanism in the mine.

Cycle: An interval of time during which a sequence of a recurring succession of events or phenomena is completed, such as a complete performance of a vibration.

Cyclonite: (See RDX.)

Damping Generator: A-c or d-c motor-driven tachometer type generator in a servo system, whose output opposes the signal which drives the motor. Also called "stabilizing" or "feedback" generator.

Danger Space: For a material target this is the distance in front of the target, measured parallel to the line of fire, that the target could be moved toward the firing point, so that a shot striking the base of the target in its original position would strike the top of the target in its new position.

Dash: Drone AntiSubmarine Helicopter. Small, lightweight, remotely controlled helicopter capable of operating from a destroyer and delivering an antisubmarine warfare weapon to an enemy submarine. It provides destroyers with a standoff weapon.

Dashpot: A hydraulic braking mechanism.

Data Transmission System: System (usually electrical) for conveying precise fire control and navigational data from one point to another.

Datum: In ASW, a reference point at which a submarine was last contacted.

D/C: (See Depth Charge.)

Dead Time: Time interval between fuze setting and firing of gun.

Decibel (db): Difference expressed logarithmically between two sounds, or a sound and an arbitrary reference level. N=10 log A/B.

Decoppering: Process of removing copper fouling from gun bore.

Deep Section Ring: (See Base Ring.)

Deep Support Fire: Fire directed on objectives not in the immediate vicinity of our forces, for neutralizing and destroying enemy reserves and weapons, and interfering with enemy command, supply, communications, and observations.

Defensive Minefield: Mines laid to deny friendly waters to enemy.

Defilade Fire: Gunfire delivered on shore targets located behind some terrain feature.

Deflection: The lateral angular correction (converted to the deck plane where necessary) which is applied to the target bearing in the deck plane to obtain gun train order.

Deflection Modulation: A principle of radar indicator functioning in which the electron beam is deflected to show a blip.

Degaussing: A method of reducing a ship's magnetic field by use of several types of coils carrying direct current around parts of the ship's hull.

Degaussing Range: An installation containing magnetic sensing devices. Ships steaming past the sensing devices cause their signatures to be recorded.

Degree of Freedom: Ability to rotate on an axis.

Degree of Readiness: Status of ship's complement, plant, and armament under specific conditions.

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Deliberate Attack (A/S): Concentrated attack to kill.

Delivery Device (in Weapon System): (See Weapon System.)

Demolition Agents: Explosives used in demolition equipment other than ammunition.

Density of Loading: Ratio of powder weight to that of a volume of water which would fill the powder chamber at a specified temperature.

Deperming: Reducing the permanent magnetic field of a ship's hull.

Depth and Roll Recorder: A device that records a torpedo's running depth and angle of roll during the run.

Depth Charge: An underwater explosive used against submarines.

Designate Hooks: Visual representation of designated target position, used in some types of target designation systems.

Designation Indicator: An equipment which displays radar or television video on the face of a kinescope (cathode-ray tube).

Destruction Fire: Fire delivered for the sole purpose of destroying material objects.

Destructor: A small, special purpose explosive charge used to destroy equipment in danger of capture, and to destroy weapons for safety reasons.

Deterrence: The prevention from action by fear of the consequences. Deterrence is a state of mind brought about by the existence of a credible threat of unacceptable counteraction.

Detonation: Violent chemical action (oxidation and recombination) initiated by a shock and producing a shock wave, heat, and gases.

Detonator: Initiating device in an explosive train.

DI: Delayed ignition (tracer).

Differential:

a. Cylinder. A piston-cylinder hydraulic device used to develop either equal thrust with unequal pressure or unequal thrust with equal pressure.

b. Mechanical. A gear arrangement used to add or subtract mechanical inputs.

c. Synchro. Either of two types of synchros used to develop a mechanical or electrical difference between or sum of two inputs.

Digital Computer: A computer, mechanical or electrical, that performs mathematical operations by counting. Cf. Analog computer.

Dip: Apparent depression angle of the horizon at sea; varies with height above sea level. Dip difference is the difference in dip at different heights.

Dip Sonar: Airborne sonar equipment lowered into the water for sonar observations from hovering aircraft. Sometimes called "dunking sonar."

Diphenylamine: A stabilizing compound used to retard deterioration in single-based powder.

Dip-Needle Mechanism: A type of magnetic mine firing mechanism.

Direct Current (or Voltage): (d-c): Current or voltage that does not reverse polarity periodically. (See Alternating current.) A direct current or voltage may fluctuate or be interrupted, but is still d-c.

Direct Fire: Gunfire delivered on a target ashore, visible to the firing ship, which uses the target itself as an aiming point.

Director: A fire control unit that establishes location of target and may furnish gun orders or other weapon positioning information.

Direct Supporting Fire: Fire delivered in support of part of a force, as opposed to general supporting fire which is delivered in support of the force as a whole.

Dispersion (of a Shot): The distance of the point of impact of that shot from the MPI of the salvo. Dispersion in range is measured parallel to the line of fire, and in deflection at right angles to the line of fire in a horizontal plane.

Distress Signal: A dual-purpose protechnic device.

Diversionary Attack: An attack wherein a force attacks, or threatens to attack, a target other than the main target, for the purpose of drawing enemy defenses away from the main effort.

Doctrine (Naval Warfare): A working principle or rule of combat that has been developed theoretically and proved by experience. Procedures are methods used to put the doctrine into effect.

Domain (Magnetic): (See Magnetic Domain.)

Dome: Underwater sonar transducer housing.

Doppler Effect: Apparent change of frequency of sound (or any other form of wave motion) when the source and the observer are in motion relative to one another.

Double-Base Powder: Solid rocket propellant usually composed chiefly of nitroglycerin and nitroguanidine.

Double-Speed (Synchro) Operation: Use of two parallel synchro systems, usually one operating at 1:1 ratio with input, and one at 36:1 ratio with input, for greater accuracy. Cf. Single-Speed (Synchro) Operation.

Dredger Hoist: A type of ammunition hoist used between handling rooms.

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Drift: (1) Deflection of projectile trajectory by interaction of gravity, air resistance, and projectile spin. (2) Rate at which water current flow moves a ship with respect to the land. (See also Set.)

Drifting Mine: A mine with no provision for maintaining a fixed position after planting. It is free to move with the waves, current, and wind. Drifting mines may watch at the surface or may be kept at a set depth by depth control devices. They are to be distinguished from floating mines which are moored mines that have broken loose. Drifting mines are no longer used by the United States.

Drone: A vehicle, land, sea, or air, which is remotely or automatically controlled.

DRT: Dead-reckoning tracer. An electromechanical automatic plotting-tracking device which continuously displays own ship position and track on a chart. Some types may also show own ship heading.

Dummy Director: Test servo (usually synchro) signal generator.

Dummy or Drill Ammunition: Ammunition without explosive or propellant.

Dunking Sonar: Sonar unit carried by helicopter, with immersible transducer lowered by cable.

Early Warning: Target information obtained before radar or optics aboard own ship acquires the target. Early warning data may be transmitted from picket ships, AEW system, radio communications, shore based observers, or operational orders.

Echo: The signal reflected by a target to a sonar or radar set to indicate target position.

ECM: Electronic countermeasures.

Effective Range: The maximum distance at which a weapon may be expected to fire accurately to inflict casualties or damage.

Effort Arm: Distance on lever arm from fulcrum to point at which effort thrust is applied.

Electrical Firing: Firing a primer by electricity.

Electrical Resolver: A special type of rotating induction device which can function as a component solver or vector solver. It contains two rotor windings 90 electrical degrees apart and two stator windings also 90 electrical degrees apart. The resolver may be used for the following purposes:

1. Resolution—to solve vectors for right angle components.
2. Composition—to combine right angle components to produce a vector.
3. Combination—to combine several vectors to produce a single sum vector.

Electric-Setting Torpedo: Torpedo whose control settings are made through servomechanisms and relays which remain connected to the fire control system until the instant the torpedo is fired.

Electric Torpedo: Unless the context clearly indicates otherwise, this term conventionally denotes a torpedo equipped with electric propulsion gear. It does not denote "electric setting" (which see) unless the context requires it. For the sake of clarity, the ambiguous term "electric torpedo" is best avoided.

Elevating Arc: Gear sector on slide used to elevate gun.

Elevating Gear: Mechanical, hydraulic, and electrical equipment used for elevating a weapon.

Elevating Nut: Part of a screw type gun elevating mechanism.

Elevation: Movement of a weapon in a plane perpendicular to the deck. Also properly called "pointing."

Elevation Alignment: Adjustment of fire control and weapon system elements so that they are in effect all parallel and all at exactly the same angle to a selected horizontal plane.

Elevation Rate: Rate of change of target elevation (position angle) in degrees per minute.

EMF: Electromotive force; usually equivalent to voltage.

Enabling (of Torpedo): Activation for pattern running or homing; in latter, exploder is also armed.

Enabling Run:

1. The straight portion of a pattern-running torpedo's run.
2. The straight portion of a homing torpedo's run, at the end of which the search pattern starts and the torpedo exploder is armed.

Energy: Capacity for Doing Work: Kinetic energy is energy in being, as that of a falling projectile or burning propellant. Potential energy is energy that can be released, such as that in a chemical propellant that has not been fired, or in a projectile about to descend from the peak of its trajectory.

Enfilade Fire: Gunfire on a ground target whose long axis is parallel to the line of fire.

Equivalent Service Rounds (E.S.R.): Standard unit of measurement of number of rounds fired from a gun for purposes of estimating resultant wear.

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Erector (Lens or Prism): Optical element which inverts a real image.

Erosion (Gun): Wear in a gun bore.

Error of the Mean Point of Impact: The distance of the MPI from the target or other reference point, measured parallel to the line of fire for range and at right angles to the line of fire for deflection.

Error Recorder: Recording device used to show servo system performance.

Error Signal: In a servo, the difference between order signal and response. Error signal is fed into the servo's amplifying device.

E-Scope: A type of fire control radar display.

ETF: Electrical time fuze.

Ethyl Centralite: (See Carbamite.)

Evaluation of Weapon System or Component: Study and appraisal of effectiveness of weapon system or component.

Exercise Head: That section of a drill torpedo or mine filled with inert and instrumentation materials, which enables training of personnel and recovery of weapons for evaluation.

Exploder: In a torpedo, the analogue of a projectile fuze.

Explosion: (See Detonation.)

Explosive: Any material that can detonate and is commonly used so that it will detonate.

Explosive D: Ammunition picrate. A notably insensitive explosive.

Explosive Ordnance Disposal Unit: Personnel with special training and equipment who render explosive ordnance safe (such as bombs, mines, projectiles, and booby traps), make intelligence reports on such ordnance, and supervise the safe removal thereof.

Explosive Train: Explosive units designed to function in sequence.

Exterior Ballistics: (See Ballistics.)

Exudate: Explosive oily substance, potentially dangerous, given off by cast TNT in storage.

Eyepiece (Lens): (See Ocular Lens (Telescope).)

Fairing: Structural additions to improve streamlining.

Fanfare: A device towed by surface ships to produce a false signal to distract enemy submarines.

Feedback (In Servo): Signal from servo output fed back to input to regulate servo action.

FFAR: The 2.75-inch folding-fin aircraft rocket ("Mighty Mouse").

Fin-Stabilized Rocket: A rocket stabilized by aerodynamic surfaces on its tail.

Fire Control: The organized system by means of which the offensive power of armament is controlled.

1. Fire Control is classified as to Type by the system employed. For each type of fire control, the battle bill of the ship specifies the instruments to be employed.
   a. Primary Fire Control. The system provided to control before damage occurs to this system; it prescribes the utilization of the principal system.
   b. Secondary Fire Control. An alternate system to give greater flexibility of control.
   c. Auxiliary Fire Control. A system provided solely to substitute for a primary system in case of damage.
   d. Local Fire Control. Control of a single gun mount or a turret from a local station in or adjacent to the mount or turret.
2. Fire Control is classified as to Method by the procedures employed in the direction of the fire of the battery.
   a. Direct Fire Control. The control procedure employed when the target is observed from the firing vessel visually or by radar.
   b. Indirect Fire Control. The control procedure employed when the target is unobserved by the fire control instruments of the firing vessel.
   c. Offset Fire Control. The control procedure employed when a point of aim of known relationship to the target is observed from the firing vessel.

Fire Control Computer: Electronic or electromechanical device which receives mathematical data and puts out fire control problem solution data. Alternately some types may be called "rangekeeper".

Fire for Effect:

1. Fire which is delivered after the mean point of impact or burst is within the desired distance of the target or adjusting/ranging point.
2. Term in a fire message to indicate the adjustment/ranging is satisfactory and fire for effect is desired.

Fire Mission:

1. Specific assignment given to a fire unit as part of a definite plan.
2. Order used to alert the weapon battery/area and indicate that the message following is a call for fire.

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Fire Support Area: An appropriate maneuver area assigned to fire support ships from which to deliver gunfire support of an amphibious operation.

Fire Support Group: A group of ships in an attack force, assigned a naval gunfire support mission.

Firing Cutout Mechanism: A device to protect own ship structure from being fired on by own ship weapons.

Firing Lock: A mechanical unit, part of the gun, which houses the firing pin or striker which contacts or strikes the primer.

Firing Pin: Metal pin that can fire primer either by electrical contact or by percussion.

Fishtailing: The weaving action of a torpedo as its steering engine throws the rudder over to right and left alternately to keep it on course.

Fixed Ammunition: Ammunition in which the cartridge case is permanently attached to the projectile.

Fixed Tubes: Torpedo tubes that cannot be trained with respect to the ship's structure.

Flammable Agent: (See Inflammable Agent.)

Flareback: Ignition of residual gases in a gun bore just after firing.

Flask Pressure Air: Air supplied direct from the torpedo air flask without reduction of pressure.

Flight Gear: In mines, any of several braking devices to reduced water impact of mines dropped from aircraft.

Floating Mine: Any mine which has broken loose from its mooring and floated to the surface. This is to be distinguished from a drifting mine which never was moored.

Fluid: A material that continuously adapts its shape to fit its container. Unless otherwise indicated, in this text the term "fluid" is equivalent to "liquid", but not to "gas".

FM:

1. Chemical agent. (See Lacrimator.)
2. A type of radio transmission in which carrier frequency is modulated.

Focal Distance (or Focal Length): Distance from center of lens to focal point.

Focal Point (Of Convergent Lens): Point at which parallel rays entering lens will meet after they emerge.

Follow-Up: (See Servo.)

Force: A pull or push on a material object that causes or tends to cause the object to move or (if moving) to change its direction or rate of motion.

Forcing Cone: (See Origin of Rifling.)

Foul Bore: Gun bore occupied by residual gases after firing. In small-arms weapons, a bore contaminated by excessive solid residue.

Frequency: Number of vibrations per unit time (generally, seconds).

FS: (See Lacrimator.)

Fulcrum: Pivot point of lever.

Fundamental: Lowest principal frequency of a sound with recognizable pitch.

Fuze: A mechanical, electrical, electronic, magnetic, or combination device used to initiate the first element in an explosive train in a projectile at the time and under the circumstances desired. It is designed to prevent initiation at other times.

Fuze Setter: A device for adjusting time fuzes just before firing.

FXP: (See NWP.)

Gain: In an amplifier, ratio of output signal strength to input signal strength.

Gas Ejector: Pneumatic device that blasts air through gun bore after firing.

Gate: In radar, the movable notch, or step, used to measure the range to a target as presented on the radar range scope. When the target is gated, the radar range dial indicates the measured target range.

Gauss: Unit of magnetic field strength.

General Announcing System (1MC Circuit): Public-address system under control of OOD.

General Requirements: Requirements applicable to all Navy ordnance or other equipment. General requirements include reliability, safety, simplicity, maintainability.

Generated Target Bearing (Relative or True): The relative or true bearing of the target as determined in a computing instrument from previous positions of own ship and target and established rate of change of bearing.

Gimbal: A metal ring or similar support free to rotate on a pivot.

GP: General-purpose (bomb).

Grass: Visible "noise" in radarscope presentation.

Grid Lines (or Zones): (See Military Grid Reference System.)

Grid Spot Converter: Graphic computer which converts spots from observer ashore into terms usable by ship's battery.

Group Control: The control of a specified group of a battery. It is concerned with the type and method of fire control, the procedures to be employed, and the acquisition

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and destruction of designated targets, as well as the detection of undesignated targets appearing in the sector of fire. Group Control is exercised by the Group Control Officer, assisted by Director Officers, Mount Captains or Turret Officers, and CIC Liaison Officers.

Guided Missile: A missile whose course may be altered during flight (as by a target-seeking radar device).

Gun: Essentially, a tube closed at one end, from which a projectile is ejected by gases from a burning propellant. The term properly applies to the tube or barrel only, but is often applied to the entire mount assembly.

Gun Chase: Outer section of a gun barrel between the slide cylinder and the muzzle bell.

Gun Defense Zone: Zone about the ship to a slant range of 10,000 yards and, for the 60° cone overhead, to an altitude of 15,000 feet (NWP 32(A)).

Gun Elevation: The vertical angle between the horizontal plane and the axis of the bore.

Gun Elevation Order: The signal transmitted to the gun indicating the gun elevation above the deck plane, measured in a plane through the bore axis perpendicular to the deck plane.

Gun Firing: The process of shooting a gun or guns.

A. Gun Firing is classified as to Means by the firing system employed.
   1. Electric Firing provides for the shooting of a gun by an electrical system controlled by either:
      a. Local Key provides for firing by means of a key actuated at the gun mount or turret.
      b. Master Key provides for firing by means of a key actuated at a station remote from the mounts or turrets, such as a director or control station.
         (1) Automatic Key is a form of master key firing in which an automatic contact maker is employed to fire at a selected firing point.
   2. Percussion Firing provides for the shooting of guns by mechanical firing mechanism at the gun mount or turret.

B. Gun Firing is classified as to Type by the rate at which guns are shot.
   1. Rapid Fire is that type of fire in which no check fire is used for purposes of applying corrections.
   2. Slow Fire is that type of fire in which the fire is deliberately delayed to allow for the application of corrections or to conserve ammunition.
   3. Deliberate Fire is that type of slow fire which is executed on a prearranged time schedule.

C. Gun Firing is classified as to Method by the manner in which individual guns are shot with respect to the other guns of the battery.
   1. Salvo Fire is the simultaneous firing of all guns ready and aimed at the same target.
   2. Full Salvo Fire is the simultaneous firing of all guns of a group.
   3. Split Salvo Fire is the firing of less than the full number of guns in a multiple gun mount or mounts at a given instant.
   4. Partial Salvo Fire is the firing of less than the full number of mounts or turrets (in multiple gunmount batteries) at a given instant.
   5. Continuous Fire is the firing of each gun without regard for the readiness of other guns of the battery.

Gun Housing: (See Housing.)

Gun Laying: The process of positioning guns in train and elevation in a predetermined relationship with respect to the line of sight. The line of sight may be established at an aloft director or generated in the plotting room, or it may be established at the gun.

A. Gun Laying is classified as to Type by the manner in which guns are positioned:
   1. Continuous Gun Laying. Guns are positioned continuously in accordance with the computed signals and loaded at any position.
   2. Intermittent Gun Laying. Guns are positioned when loaded, but must be returned to a specified position after firing for loading.

B. Gun Laying is classified as to Method by the means by which guns are positioned.
   1. Automatic Gun Laying. Guns are positioned automatically by remote control systems in accordance with signals received.
   2. Indicator Gun Laying. Guns are positioned locally in accordance with signals received. Positioning may be effected by either local power or manual drive.

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3. Local Gun Laying. Guns are positioned locally, by gun-sight telescope. Positioning may be effected by either local power or manual drive.

Gunnery: Operation and control of all elements of armament.

Gun Range: Range listed in the range table corresponding to gun elevation.

Gunsight Alignment: Includes those operations in battery alignment that involves the mechanical alignment of the parts making up each element—viz, alignment within each mount, turret, or gun of the battery.

Gun-Target (GT) Line: An imaginary straight line from a weapon to a target. (Same as Weapon-Target Line.)

Gun Train Order: Signal transmitted to the guns indicating the angle in the reference plane from own ship's bow clockwise to the perpendicular plane through the axis of the bore.

Guppy: A modified fleet-type submarine. Acronym from Greater Underwater Propulsion Power (project).

Gyroscope (Gyro): A device which uses the rotational inertia of a spinning wheel to establish a reference direction or plane in space, or to provide displacement in another direction proportional to any force that tends to twist the wheel's axis.

Hand Control: On certain electric-hydraulic gun mount power drives, a mechanical-hydraulic servo control by mount personnel.

Handling Room: Compartment aboard ship used for transporting and to some extent for stowage of ammunition.

Hang Fire: Accidental delayed ignition of primer, igniter, or propelling charge.

Harmonic: Any frequency higher than the fundamental of a sound; a frequency with relatively simple mathematical relationship to a fundamental frequency. Also called "partial".

Harassing Fire: Sporadic support fire designed to disturb the rest of the enemy troops, to curtail movement and, by threat of losses, to lower morale.

HBX (—1 and —3): Explosive mixtures of TNT, RDX, aluminum powder, and desensitizer.

HC: High-capacity gun projectile. Equivalent to HE in Army nomenclature.

Head (Liquid Pressure): Hydrostatic pressure.

Head (of Torpedo): (See Warhead and Exercise Head.)

Headlight: A light in a torpedo exercise head which is illuminated at the end of the run to assist the torpedo recovery crew to locate the torpedo.

Hedgehog: 7.2" antisubmarine warfare, ahead-thrown, short-range weapon.

Hexogen: (See RDX.)

H/H: (See Hedgehog.)

High Explosive: Any detonating compound or mixture, such as Explosive D, TNT, RDX, HBX, etc.

Hitting Gun Range: Gun range corrected for the error of MPI.

Hitting Space: The distance measured parallel to the line of fire between a shot striking the top of the target and one striking the waterline on the engaged side of the target.

Hoisting Lug: A lug used for hoisting a bomb into aircraft. Not used for suspending the bomb in the aircraft.

Holding-Down Clips: Parts that secure base ring against being tipped out of training circle.

Homing: The final stage of a homing torpedo's run, in which it steers itself toward a target it has detected. Applied also to any target-seeking device.

Homing Torpedoes: Torpedoes with target-sensing capabilities.

Horizon Check: Comparison of elevation dial readings when battery element is laid successively on a series of points on the horizon.

Horizontal Plane: A plane tangent to the earth's surface or parallel to such a plane.

Horizontal Range: Horizontal component of slant range.

Horizontal-Type Torpedo Engine: Torpedo engine in which the turbine axis is horizontal rather than vertical (the more conventional arrangement in gas-stream torpedoes).

Housing (Gun): Chief support of recoiling gun parts; houses breech mechanism.

H-Type Torpedo Engine: (See Horizontal-Type Torpedo Engine.)

Hunter/Killer Force: A naval force consisting of an antisubmarine warfare carrier, associated aircraft and escorts combining specialized searching, tracking, and attacking capabilities of air and surface antisubmarine warfare units operated as a coordinated group for the conduct of offensive antisubmarine operations in an area of submarine probability.

Hunter/Killer Operations: Offensive antisubmarine operations in a submarine probability

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area, combining the best searching, tracking, and attacking capabilities of air, surface and subsurface units and forces in coordinated action to locate and destroy submarines at sea.

Hunting: In servosystems, a tendency for the output to oscillate because of weak signal, insufficient feedback, excessive gain, or malfunction.

HVAR: 5-inch high-velocity aircraft rocket.

Hydraulics: Study of behavior of liquids in enclosed systems. In this text, this is expanded to include the study of liquids at rest in open systems (hydrostatics).

Hydraulic Speed Gear: Combined A-end and B-end, with accessories, piping, etc.

Hydrogen Eliminator: A device on electrically driven torpedoes which is designed to dispose harmlessly of hydrogen evolved by lead-acid storage batteries. Also called a "hydrogen burner."

Hydrophone: Underwater listening device; passive sonar.

Hydrostatic Pressure: Pressure developed by weight of liquid above the point of measurement, as distinct from applied pressure transmitted through the liquid.

Hydrostatics: Behavior of liquids in open systems. Cf. Hydraulics.

IFF: Identification friend or foe—a means of challenging and identifying aircraft and ships by radar.

Igniter: Unit in a propellent train that sets off the propellant.

Illuminating Projectile: A projectile containing a chemical flare and parachute. Abbreviation: Illum.

IMP: Integrated Maintenance Plan is a part of PMS which in turn is a part of the Standard Navy Maintenance Management System.

Impact Action Fuze: A fuze that is set in action by the striking of a projectile or bomb against an object, e.g., percussion fuze, contact fuze.

Impulse Charge: A charge using black powder as a propellant; formerly used to eject depth charges and torpedoes from their launching devices.

Incident Ray: Ray (usually of light) striking a surface or boundary.

Independent Mine: Mine actuated automatically after planting and arming.

Index (of Propellant): A blend of several lots of propellant powder.

Indicator-Receiver-Regulator: (Usually abbr. to "indicator-regulator"). Controlling equipment for weapon mount power drives. Some types are called "receiver-regulators."

Indirect Fire: Support from fire delivered on a target ashore which is not itself visible from the ship, or available for use as a point of aim.

Inertia: Resistance of a mass to acceleration.

Inflammable Agent: An incendiary chemical agent, such as WP (white phosphorus).

Influence Exploder: Any type of exploder that functions when the torpedo is close to the target.

Influence Explosion: (See Sympathetic Explosion.)

Influence Mine: Mine that detonates when target approaches or passes near. Such mines may have magnetic, acoustic, or pressure-sensitive mechanisms.

Inherent Corrections: Fire control problem corrections for motion of gun platform, parallax, and divergence of gun mount roller paths from deck plane.

Inhibitor: Plastic strip used to slow the burning rate of solid rocket propellant.

Initial Ballistic Correction: That part of the ballistic corrections not automatically compensated for by the fire control system.

Initial Forcing Pressure: Propellent gas pressure required to initiate movement of projectile in gun base.

Initial Velocity (I.V.): Speed of projectile in feet per second at muzzle of gun.

Instrument Servomotors: Small fractional horsepower a-c servomotors.

Intensity Modulation: A principle of radar indicator functioning in which the electron beam is intensified to show a blip.

Intensity (of Sound Vibration): Equivalent to amplitude of vibration. (See Amplitude.)

Intensive Incendiary Bomb: Incendiary bomb using thermite.

Intercept Search: A type of passive ECM.

Intercom System: Two-way type of battle announcing system.

Interdiction Fire: Fire designed to deny the enemy ashore the use of a given route of communication, airfield, bridge, etc.

Interdirector Designation: The transmission of repeat-back information of a director to another director for the purpose of tracking the same target.

Interior Ballistics: Projectile motion and behavior while in the bore of a gun.

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Internal Alignment: Adjustment of geometrical relationships within an element of a fire control or weapon system.

Jamming: Radiating interference or deceptive signals.

Jettison: To eject explosive weapons for safety reasons.

Joystick: In target designation equipment, a component used to control the output signal of dual potentiometers. These signals position designator symbols on a display and are used for transmitting target position coordinates to the converter.

Kinetic Energy: (See Energy.)

Lacrimator: A chemical agent that causes weeping and irritation of the throat and lungs. Example: CH (Chloracetophenone).

Ladders: A succession of salvos fired with known and predetermined changes between successive salvos, to ensure early establishment of hitting gun range and deflection in surface fire, to serve as a yardstick for covering an area target, or to increase pattern size.

A. Ladders are classified as to Type by the element in which laddering takes place.
   1. Deflection Ladders are ladders fired with predetermined changes in deflection on successive salvos. They are seldom used in our Navy, except for covering area targets or in radar spotting when the discrimination of fire control radar makes a deflection rocking ladder advisable.
   2. Range Ladders are ladders fired with pretermined changes in range on successive salvos.
   3. Elevation Ladders are ladders fired with predetermined changes in elevation between successive salvos. They are seldom used in our Navy.

B. Ladders are classified as to Method by the manner in which the predetermined arbitrary corrections are introduced.
   1. Initial Ladders are ladders in which, in addition to known increments or steps, the number of salvos is definitely known. This number is greater than two, and the steps are sufficiently large, so that the target will be located within the limits of the ladder.
   2. Add Ladders are fired with the initial gun range less than the best range and with successive steps of the ladder fired with increasing ranges, each increasing range spot not less than the pattern size.
   3. Drop Ladders are fired with the initial gun range greater than the best range and with successive steps of the ladder fired with decreasing ranges, each decreasing range spot not less than the pattern size.
   4. Continuous Ladders are fired with a continuous application of spots, applied in such a manner as to move the salvos back and forth across the target.
      a. Spotter-Controlled Ladder is a form of continuous ladder in which the spotter or observer determines all or part of initial direction, when to change direction, size of first ladder steps, and when the ladder is reversed. For simplicity, the size of steps of the first ladder and successive ladders is usually prearranged. The initial correction of the first ladder may be directed by doctrine or other orders.
      b. Rocking Ladder is a form of continuous ladder in which the number of steps of the ladder before reversal of direction and the size of the steps are both specified beforehand. The object is to increase the pattern size and still maintain sufficient projectile density to ensure hits. The steps of the ladder are never larger than the pattern size, and the number of steps is such as will ensure covering probable ranging and aiming errors and target maneuvers during time of flight. If used with continuous fire the steps are applied at regular predetermined time intervals; if with salvo fire, after each salvo.

Lamé's Law: States relationship between tangential tension and radial pressure with variation of radius in cylinder under fluid pressure.

Land (in Rifling): High part between grooves.

Laws of Reflection:
1. Angle of incidence equals angle of reflection.
2. Normal, incident ray, and reflected ray all lie in the same plane.

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Layer Depth: The depth from the surface to the top of a sharp negative gradient. Under positive gradient conditions, the layer depth is the depth of maximum temperature.

Lethal Gas: A type of poisonous chemical agent injurious when breathed or on contact. Example: Phosgene.

Level Angle: Inclination of the battery reference plane with the horizontal, measured in a plane that contains the line of sight. The latter plane may be either the vertical or a plane perpendicular to the reference plane, depending on the design of the control equipment.

Lewisite: (See Vesicant.)

Light Ray: An imaginary line used to show the direction in which a light wave is moving.

Limpet Mine: A mine attached by a diver to the hull of the enemy ship.

Line of Fire (LOF): The straight line joining the gun and the point of impact (or burst) of the projectile. As used in safety precautions for target practices, the line of fire is assumed to include all points near the bearing of the line of fire.

Line of Sight (LOS): Straight line joining the sight and the point of aim.

Line of Sight Coverage: The distance to which radar is limited because the radiated waves do not follow the curvature of the earth.

Liner: A cylindrical insert in the gun tube, in which (in some guns) the rifling grooves are engraved.

Loading Dead Time: The time between the instant a projectile is removed from the fuze pot and the instant of firing that projectile. For practical purposes, when firing mechanical-time-fuzed projectiles, the average loading dead time of the battery is the dead time for which correction must be made.

Loading Factor (of a Bomb): Ratio of explosive weight to total bomb weight.

Lobe: In radar, a plot of all points in the radar beam which present an equal signal from an identical target, assuming antenna bearing remains fixed.

Local Control: Control of a gun mount through signals originating at the mount.

Lock Combination Primer: A separate-loading primer that fits into a firing lock.

Lock On: Signifies that a tracking or target seeking system is continuously and automatically tracking a target in one or more coordinates (e.e. range, bearing, elevation).

Longitudinal Waves: Vibrations parallel to direction of wave front movement, causing alternate rarefactions and compressions (compression waves).

Look: In magnetic firing devices used in underwater ordnance, an actuating pulse caused by the change in earth's magnetic field resulting from movement of the firing device or a ferrous target with respect to each other.

LOS: Line of sight. (See also Sight.)

Low-Drag Bomb: An aircraft bomb streamlined for minimum drag at supersonic speed.

Lower Carriage: (See Base Ring.)

Low-Speed (Synchro): Synchro rotating in 1:1 ratio with input. Also called "coarse" unit.

M: Fire control symbol for roll signal. Also used as equiv. of Mk in Army ordnance nomenclature.

Machine, Basic: Any device that helps to do work. There are only six basic machines: the level, the block and tackle, the wheel and axle, the inclined plane, the screw, and the gear. Complex machines are merely combinations of two or more basic machines.

MAD (Magnetic Airborne Detection) Equipment: Underwater target detection equipment of magnetic type carried by fixed-wing aircraft.

Magazine: Compartments aboard ship designated for ammunition stowage.

Magnetic Domain: Group of molecules that acts as a magnetic unit in a magnetic substance.

Magnetic Flux: Magnetic lines of force; magnetic field strength.

Magnetostriction: Change in shape in a metallic object caused by a magnetic field.

Major Caliber (Gun): Gun of 8-inch or larger caliber.

Manual Control: Local control and positioning of a gun mount without use of power equipment.

Mass: Quantity of matter in a body.

Massing of Fire: Fire from a number of weapons, or from two or more ships, directed against a single target.

MCC: Maintenance of close contact (a type of sonar transducer coil).

Mean Battle Range: Range at which a gun is most effective. This range is the one at which the gun sights may be boresighted.

Mean Point of Impact: The geometrical center of points of impact of all projectiles which are fired or released at the same aiming point at approximately the same time.

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Merry-GO-Round:
1. Drum magazine in Mk 108 rocket launcher.
2. Rotating cage used in ammunition transfer in some 5-inch gun mounts.

Micron: 1/1000 mm.

"Mighty Mouse": (See FFAR.)

Mil: Unit of angular measure in naval gunnery, used to specify sight deflection. One mil is the angle whose tangent is 0.001 (arc tan 1/1000), or about 0.06° (3.44'). With 6400 mils = 360°, the mil is used by ground artillery spotters to specify target bearing.

Military Grid Reference System: Method of designating areas of earth's surface by a standard pattern of perpendicular grid lines.

Military Requirements: Statement of nature and capabilities of weapon or allied equipment and systems. Capabilities are related to the purpose or task assigned to the equipment etc. in question.

Mine: Underwater explosive weapon actuated when approached or touched by a target.

Mine Countermeasures: All methods for preventing or reducing damage or danger to ships, personnel, aircraft, and vehicles from mines.

Mine Hunting: The branch of mine countermeasures based on determining the positions of individual mines and concentrating countermeasures on those positions, as opposed to techniques directed at a more extensive area suspected of containing mines.

Minor Caliber (Gun): Gun of caliber over 0.60 inch but under 4 inches.

Misfire: Failure of primer to ignite when firing action is initiated.

Mk (Mark): Mark (followed by a number) identifies an equipment design type. To identify a particular model, it is necessary to specify modification (mod) number in addition.

Mobile Mine: A submarine-planted, hybrid weapon combining features of an electric torpedo and a mine.

Momentum: Tendency of a mass in motion to continue moving.

Moored Mine: A mine having a buoyant case that is held at a predetermined depth after planting by a cable or chain attached to an anchor.

Mount (Gun): The structure which supports the gun and enables it to be elevated, trained, and fired.

MTF: Mechanical time fuze.

Multi-Based Powder: Gun propellant composed chiefly of nitrocellulose, nitroguanidine, and nitroglycerine.

Mustard (Gas): (See Vesicant.)

Napalm: A powder employed to thicken gasoline for use in flame throwers and incendiary bombs.

Naval Gunfire Liaison Team: Personnel and equipment required to coordinate and advise ground/landing forces on gunfire employment.

Naval Gunfire Spotting Team: The unit of a shore fire control party which designates targets, controls commencement, cessation, rate and types of fire, and spots fire on the target.

Navigational Range: The best distance to the target, used in post-firing analysis.

Navol: H_2O_2 (hydrogen peroxide) in high concentration, used to supply oxygen for fuel combustion chemical torpedoes.

Navy Light: A hand-held pyrotechnic device.

Negative Buoyancy: Tendency to sink.

Negative Temperature Gradient: Density pattern in sea water tending to bend sonar sound path downward.

Neutralization Support Fire: Support fire intended primarily to hamper, intempt, or prevent enemy movement or action.

Newton's Laws of Motion:
1. A body at rest tends to remain at rest and a body in motion tends to continue moving in a straight line unless the body is acted on by some unbalanced force.
2. Acceleration of a body in response to a force is directly proportional to the force, inversely proportional to the body's mass, and is the direction of the force.
3. To each action there is an equal and opposite reaction.

Nitrocellulose: (See Pyrocotton.)

Nitrocotton (Nitrated Cotton): (See Pyrocotton.)

Noise:
1. Unorganized sounds.
2. Signals other than and interfering with the signal desired.

Nominal Initial Velocity: The initial velocity assigned a new gun with the propellant at a temperature of 90° F.

Nonautomatic (Gun): Gun in which none of the energy of the propellant is used to perform breech operations or ammunition loading or ejection.

Nonfrag: Nonfragmenting projectiles used in AA gun practice. They produce a colored smoke but no fragments when they detonate.

Nonhoming Torpedo: A torpedo without target-seeking capabilities.

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Normal: Perpendicular to a surface or boundary.

Nose Cap: Armor-penetrating part of AP projectile.

Nuclear Weapon: A device in which the explosion results from the energy released by reactions involving atomic nuclei, either fission or fusion, or both.

Null: In servo terminology, equivalent to servo signal level. "Zero" implies complete absence of a signal; "null" implies no perceptible signal, although noise and other random nonsignal voltages may be present.

Nutate: To oscillate through a small angle in a specific pattern.

NWIP: (See NWP.)

NWP: Naval Warfare Publication. (Also called COMMTAC (COMMunications—TACtical) publications.) Any of a series of Navy publications on doctrinal and related matters. Related publications include Allied Tactical Publications (ATP's), Allied Communications Publications (ACP), Fleet Exercise Publications (FXP's), Allied Exercise Publications (AXP's), and Naval Warfare Information Publications (NWIP's).

Objective: An area or location which a troop unit is assigned to occupy or capture.

Objective (Lens): Telescope lens which forms inverted real image.

Observer-Target (OT) Line: Line joining the naval gunfire shore spotter and the target.

Ocular Lens (Telescope): Lens which makes an enlarged visual image of real image formed by objective lens.

OD: Ordnance Data—BuWeps publications containing reports of inspection and test data, primarily for use by inspectors and research personnel. ODs also contain ordnance equipment lists which provide planning information for the Bureau of Naval Weapons and the Bureau of Ships.

Offensive Minefield: Minefield laid in enemy waters to prevent movement of ships or to destroy them.

Otter: A type of underwater kite used in minesweeping.

Offset Centerline: In drydock battery alignment, a line established ashore parallel to the drydocked ship's centerline.

Ogive: Forward curved or conical part of a projectile.

Ohm's Law: $I = \frac{E}{R}$.

Oil Gel: Sticky combustible liquid that constitutes the active ingredient in scatter incendiary bombs.

OP: Ordnance Pamphlet—The basic BuWeps publication relating to specific ordnance equipment or data for field and fleet use.

Opportunity Fire: Fire delivered impromptu on newly discovered or transitory targets.

Optical Axis: Axis of a lens, on which light rays are not bent when entering or leaving the lens.

Ordalt: ORDnance ALTeration. A prescribed change in ordnance equipment.

Order Signal: In a servo, a control signal from outside the servo.

Ordnance: Weapons and physical equipment pertaining to them. Aboard ship it includes everything referred to as "ship's armament."

Ordnance Allowance Lists: Lists of required ordnance material for naval organizations afloat and ashore.

ORI: Operational Readiness Inspection.

Origin of Rifling (in a Gun): Where the rifling lands start, just forward of the chamber. Approximately the same location as the "forcing cone."

OT: Observer-Target line from ground observer to target ashore (used in target-grid system).

OTC: Officer in Tactical Command.

Oxidation: Combination of oxygen atoms with other atoms or atomic groups (molecules).

Parallax: The angular difference which results from making observations or computations to one target from two different stations. Train, or horizontal, parallax is the angular difference measured in the horizontal plane. Elevation, or vertical, parallax is the angular difference measured in the vertical plane.

Parallax Error (in a Telescope): Apparent target displacement when the eye is shifted about the optical axis of the eyepiece.

Partial: (See Harmonic.)

Pattern (of a Salvo in Range): The distance measured parallel to the line of fire, between the shot of the salvo, falling or bursting at the greatest distance from the firing point and the shot falling or bursting at the shortest distance, excluding wild shots. In deflection it is the distance measured at right angles to the line of fire between the shot falling or bursting at the greatest distance to the right and the shot falling or bursting at the greatest distance to the left, excluding wild shots.

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Pattern Running (Torpedo): An alternative type of run possible with some nonhoming torpedoes. Consists of a straight enabling run followed by a period of running continuously in circles of fixed radius.

PDF: Point Detonating Fuze.

Pellicle: A half-reflecting half-transparent optical unit.

Percussion (Fire): Firing a primer by mechanical impact.

Permeability: Ability to conduct a magnetic field.

Phase: Angular relationship between two alternating currents or voltages, e.g. between a signal voltage and a reference voltage, when the voltage or current is plotted as a function of time. When the two are in phase, the angle is zero, and both reach their peak simultaneously. When out of phase, one will lead or lag the other; at the instant when one is at its peak, the other will not be at peak value, and (depending on the phase angle) may differ in polarity as well as magnitude.

Phosgene: (See Lethal gas.)

Pillenwerfer: Bubble-making device used by submarines to create a distracting target.

Ping: Transmitted or received sonar pulse.

"Ping" Sonar: Active sonar.

Pinger: An ultrasonic transistorized transmitting device used in locating lost drill torpedoes and mines.

Pip: Element of radar or sonar video presentation. (Preferred word is blip).

Pitch: Ship movement in response to wave motion measured in a vertical plane containing ship's centerline. In fire control, it is the instantaneous value of the angle between the reference plane and the horizontal, measured in a fore-and-aft vertical plane. Note: For purposes of naval gunnery both roll and pitch are measured and recorded as rates; that is, in terms of amplitude per unit time, ordinarily as total degrees of roll (or pitch) per minute.

Pitch (Sound): Audible quality of sound which depends on the sound's dominating frequency.

Plan Position Indicator (PPI): A CRT or screen which displays target position, director position, and designation symbols. The data appear as a result of a rotating sweep moving at a rate fast enough to prevent fading of this information. It indicates azimuth by direction of the radial line, and range by the distance of the echo signal from the center of the screen.

Plaster-Loaded or Sand-Loaded Ammunition: Like service ammunition but with inert load in place of burster.

Plug: (See Breechblock.)

Plug Gage: Instrument used to check adequacy of clearance in gun bore.

PMS: Planned Maintenance System is a part of the Standard Navy Maintenance Management System.

Point Fire: Support gunfire directed at a specific target for its destruction.

Point of Aim: That point on a target at which the sight is directed.

Point Oscar: Method of indirect fire.

Pointer: One who moves a weapon in elevation.

Pointing: (See Elevation.)

Polaris: An underwater/surface-launched, surface-to-surface, solid-propellant ballistic missile with inertial guidance and nuclear warhead.

A-1 - 1200 nautical mile range.
A-2 - 1500 nautical mile range.
A-3 - 2500 nautical mile range.

Position Angle: The vertical angle between the horizontal and to the line of sight to an elevated target.

Positive Buoyancy: Tendency to float.

Potential Energy: Energy available to do work.

Potential (of a Propellant): Total work that the gases of combustion could perform while expanding from solid state to the space they would occupy when fully expanded to atmospheric pressure and cooled to a specified temperature.

Potential Energy: (See Energy.)

Powder Fouling: Propellent residue left in gun bore and chamber after firing.

Power: Time rate of doing work.

Prearranged or Schedule Support Fire: Gunfire formally planned against targets at known locations.

Predicting: The process of determining future target position. Predicting operations are accomplished in computers simultaneously and automatically with tracking.

Preheater (Torpedo): Coil of tubing in turbine exhaust, used to heat air being fed to reducing valve.

Preliminary (Shore) Bombardment: Bombardment of objective area by an advance force to destroy enemy defenses.

Preparation Fire: Prearranged neutralization support fire delivered just prior to a ground attack or landing by friendly forces.

Pressure: Force per unit area.

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Present Range: The best available measurement of the range to the target.

Primary Explosive: Any very sensitive explosive, such as mercury fulminate, DDNP, nitromannite, lead azide, lead styphnate, tetracene.

Prime Mover: A driving machine, such as an electric motor.

Primer: First unit in a propellant train.

Prism: Optical light-transmitting element with flat surfaces. May utilize total internal reflection.

Prismatic Sight: Any sight using prisms in its optical system.

Procedure (Naval Warfare): (See Doctrine.)

Programming: Setting up automatic equipment to perform operations in prescribed sequence.

Proof Run: A torpedo exercise run made before issue to the fleet.

Propellent (Adjective): Relating to or functioning as a propellent.

Propellent Train: Propellent-igniting units designed to function in sequence. Analogous to explosive train.

Propelling Charge (Propellant): Any mixture or substance that reacts or burns rapidly (usually incorporating most of its oxygen) but does not detonate, and is commonly used to propel a rocket, gun projectile, etc.

Prototype: An early (usually the first) installed model of equipment; model for later quantity production.

Proximity Fuze: A fuze designed to detonate a projectile, bomb, mine, or charge when activated by an external influence in the close vicinity of a target. The variable time fuze is one type of a proximity fuze.

PSI: Abbreviation for pounds per square inch.

Pyrocotton: Principal constituent of single-base powder. A form of nitrocellulose. Pyrotechnics: Munitions designed to produce light or smoke for illumination or signaling.

Quality: Characteristic "color" of sound that depends on harmonic content, method of production, etc.

Radar: Radio Detection And Ranging equipment that determines the distance and usually the direction of objects by transmission and return of electromagnetic energy.

Radar Scope: CRT used as radar video display device. The following types are used:

A. Scope. An indicator with a horizontal or vertical sweep indicating range only. Signals appear as vertical or horizontal deflection on the time scale.

B Scope. Type of presentation on which the signal appears as a bright spot with azimuth angle as the horizontal coordinate and range as the vertical coordinate.

E Scope. A modification of the B scope. Signal appears as a bright spot with range as the horizontal coordinate and elevation as the vertical coordinate.

PPI Scope. (See Plan Position Indicator.)

Radially Expanded (Gun): A type of prestressed gun barrel.

Range: Distance from a station on own ship to the target or some other designated point.

Rangefinder: Optical device that measures range to target.

Rangekeeper: (See Fire Control Computer.)

Range Marks: In target designation displays, pips or traces superimposed on the video signal and supplied to a cathode ray tube at specific intervals to show calibrated range indications.

Range Rate: Rate of change of range in yards per minute caused by relative motion of own ship and target.

Range-Table Initial Velocity: The initial velocity for which the range table is computed.

Ranging: The process of establishing target distance from the firing ship.

A. Ranging is classified as to Means by the instrument employed:

1. Radar Ranging describes determination of target distance by radar.
2. Optical Ranging describes determination of target distance by a rangefinder.
3. Generated Ranging describes the generation of target distance by a computer.
4. Estimate Ranging describes the determination of target distance by estimation.
5. Navigational Ranging describes the determination of target distance by navigational means.

B. Ranging is classified as to Type by the frequency with which the range is established.

1. Continous Ranging is that type of ranging in which target distance is continously established.
2. Intermittent Ranging is that type of ranging in which target distance is established at intervals.

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C. Ranging is classified as to Method by the procedure employed to operate the instrument.
   1. Manual Ranging is that method of ranging in which the ranging instrument is operated by hand.
   2. Aided Ranging is that method of ranging in which the generated change of range is introduced into the ranging instrument and upon which corrections are superimposed manually by the rangefinder or radar operators, as required.
   3. Automatic Ranging is that method of ranging in which the instrument automatically determines target distance of an acquired target.

Rapid Fire (RF): RF guns are those in which loading, firing, empty-case ejection, and breech operation are performed automatically by power from a source other than the propellant, and other than manual.

Rate of Climb: Rate of change of altitude measured in feet per minute or in knots.

Rate of Fire: The number of rounds fired per weapon per minute.

RDX: A high explosive. For composition, see appropriate OP. Main constituent of compositions A, B, C, Hexogen, Cyclonite.

Real Image: An optical image that exists where perceived.

Recoil: Rearward thrust on gun produced when gun fires; movement of gun parts in response to this thrust.

Recoil Mechanism: Mechanical or hydraulic brake that absorbs some of the energy of recoil.

Recuperator: (See Counterrecoil.)

Reduced-Pressure Air (Torpedo): Air supply at around 125 psi, used to sustain gyro spin.

Reference Plane: An arbitrarily chosen plane, usually within the ship, from which angles of elevation of all battery elements are measured. In practice, it may be the plane containing one of the battery roller paths, or it may be an imaginary plane.

Reference Supply: A-c voltage of specified frequency and phase supplied to energize synchro and a-c servo systems. Usual reference frequencies are 60 cps and 400 cps.

Reference Voltage: Ship's a-c supply, used to energize power supplies and a-c servomotor fields.

Refraction: Bending of light or sound beam when passing through media of different density.

Refractive Index: Ratio of optical density of a light-transmitting medium to that of a vacuum.

Relative Target Bearing: The bearing of the target from the firing ship, measured in the horizontal plane from the bow of own ship clockwise from 0 degrees to 360 degrees.

Relief Valve: A valve that automatically opens to relieve excessive pressure. A safety valve is a type of relief valve.

Repeat Back: In target designation procedure, a report from director to designator affirming that target is being tracked.

Repeat-Back Hook: Visual feature of some types of TDS, used to show director position.

Repeater: Duplicate indicator.

Resistance Arm: Distance on lever arm from fulcrum to load point.

Response: In a servo, the movement effected by servo operation, or a signal based on it. This signal is fed back to the error-sensing device at the system input. Also called "feedback."

Restricted Weapons: Nuclear, biological, and chemical weapons (sometimes called "NBC" weapons).

Reticle: A reference mark or pattern in an optical system, visible to the user of the system.

Returnable Quota: A quota under which a crewman sent to school from a ship is returned to the ship after his training is completed.

Reverberation: In sonar, multiple echoes that tend to mask the target echo.

RF (Guns): (See Rapid Fire.)

Rifling: Spiral grooves in the inner surface of the gun bore.

Ring Sight: A type of nonmagnifying sight using concentric rings to aid in establishing lead angle.

Ripple Switch: A rotary multiple-contact switch used to fire a salvo of hedgehog charges in rapid succession.

Rocket: A missile not guided after launching propelled by reaction thrust evolved from burning of a fuel with oxygen supplied by the rocket.

Roll: The instantaneous value of the angle between the reference plane and the horizontal, measured in an athwartship vertical plane.

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Roller Path: Roller bearing on which a weapon mount or fire control element trains.

Roller Path Compensator: A mechanical device which automatically introduces a compensating tilt at all train angles to correct for tilt of a roller path.

Roller Path Data: Tabulated measurements of inclination of a trainable battery element at various train angles.

Rotating Band: Annular part (usually of copper) on a projectile which is engraved by the gun bore's rifling when the projectile is fired.

Rotor: A part that revolves in a stationary part such as the rotating member of an electrical machine.

Run-Down Gyro: A torpedo gyroscope mechanism which coasts for the duration of the run after an initial spinning impulse.

Safety Link: Metal link designed to hold gun in battery when counterrecoil system fails or is deactivated.

Safety Valve: (See Relief valve.)

Salvo: One shot or several shots fired simultaneously or nearly so by the same battery at the same target.

Salvo Buzzer: A buzzer operated by the computer time-of-flight mechanism to warn of impending salvo burst or splashes.

Salvo Latch: Mechanical interlock designed to prevent accidental opening of gun breech in event of misfire or hang fire.

Sand-Loaded Ammunition: (See Plaster-Loaded Ammunition.)

SAP: Semi-Armor-Piercing (bomb).

SAU: In ASW, a search attack unit.

Scanning Sonar: (See Azimuth Search Sonar.)

SCAR: A type of 2.25-inch aircraft practice rocket.

Scatter Incendiary (Bomb): Oil-gel loaded incendiary bomb.

SC Device: A search coil used in a magnetic induction mine to detect passing ships by their distortions of the earth's magnetic field.

SCD (Sonar Display): Sonar display of PPI-type using own ship as center.

Screening Fire: Support gunfire using smoke projectiles to obstruct enemy view of friendly units and movement.

Sea Battery: An electric battery in which sea water is the electrolyte.

Seapower: "That portion of a nation's overall power which enables it to use the sea in furtherance of its interests, objectives, and policies." (NWP 10(A))

Searchlight Sonar: Sonar system (now largely supplemented by azimuth sonar except for special applications) in which pulse is transmitted and received in a narrow beam.

Section: Primary organizational unit of a ship's crew.

Sectional Density: Weight of gun projectile per square inch of bore.

Sector Control: The control of one group of a battery, or two or more groups of different batteries, each of which is assigned the same sector of fire. It is concerned with the acquisition and destruction of designated targets appearing in the sector. Sector Control is exercised by the Sector Control Officer, assisted by Group Control Officers, and CIC Liaison Officers.

Sector of Fire: A specific area assigned to a unit or to a weapon to cover by fire.

Self-Destroying Fuze: A fuze designed to burst a projectile before the end of its flight.

Semiautomatic (Gun): Case gun in which some of the propellant's energy is used to open the breech, eject the empty case, and close the breech when the next round is loaded.

Semifixed Ammunition: Ammunition in which the cartridge case is not permanently attached to the projectile.

Separate-Loading Ammunition: (See Bag Ammunition.)

Service Ammunition: Complete ammunition assemblies fit for service.

Series Motor: An electric motor whose field winding is in series with the armature winding.

Servosystem Or Servo: Any of a variety of systems in which a relatively powerful driving unit responds to a relatively weak signal, and in which the response is fed back to the sensing device at the input end of the system so that it may be compared to the incoming signal and the operation of the driving unit controlled correspondently. A "servomechanism" (also called a "follow-up") is usually an electrical arrangement of this kind in which the mechanical output is produced by an electric servomotor.

Servomotor: The unit in a servosystem that drives the load, especially the electric-drive motor in a servo-mechanism or in gun elevating or training gear.

Set: Direction of ship's drift due to ocean or river current. (See also Drift (2).)

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Setback: Rearward force exerted on fuze parts when projectile accelerates.

Shimming: Method of obtaining a proper level or a correct spacing tolerance by adding thin strips.

Ship Heading Line: Visual display of own-ship heading in TDS.

Shore Fire Control Party: A specially trained unit for control of naval gunfire in support of troops ashore, consisting of a spotting team to adjust fire and a naval gunfire liaison team.

Sight: Optical device that establishes line of sight (LOS) to target and provides for positioning of weapon or director with respect to LOS.

Sight Angle: The vertical component of the angle between the line of sight and the axis of the bore.

Signal-To-Noise Ratio : Mathematical statement of signal strength as related to interference.

Signature: The characteristic magnetic pattern of a ship's hull as it moves past a magnetic sensing device.

Silent Running: Aboard a submarine, the state of operating in which a minimum of noise is radiated.

Simple Elevation Check: Horizon check performed at but one point on the horizon.

Single-Base Powder: Gun propellant composed of nitrocellulose, stabilizer (diphenylamine), and ether-alcohol mixture.

Single-Speed (Synchro) Operation: Use of one synchro system to transmit shaft rotation data in 1:1 ratio with original signal. Cf. Double-Speed (Synchro) Operation.

Sinking Detonator: A means of rendering a mine safe.

Slant Range: Distance to an aerial point or target.

Slide: Structural support for all parts of gun mount that move in elevation.

Slide Cylinder (of Gun): Cylindrical after part of barrel.

Slipring: Rotating annular contact.

Small Arms (Caliber): 0.60 inch or smaller.

Smokeless Powder: SPCG or single-based gun propellant.

Socket Ring: A part of an axial-piston pump which can be adjusted to regulate pump output.

Sonar: Use of sound in underwater target detection and location. (Acronym from SOund NAvigation and Ranging.) Sonar may be active (radiating pulses) or passive (listening only).

Sonar Control Indicator: Main control component in a sonar system, at which a Sonarman is stationed.

Sonar Dome: Sonar transducer housing.

Sonics: Sounds audible to the normal human ear.

Sonobuoy: Floating radio transmitter dropped from fixed-wing aircraft and fitted with underwater microphones. Used in ASW.

SPCG: A multi-base gun propellant. Also called Cordite N.

Spend Brass: Used cartridge cases.

Spigot: Part of hedgehog projector; by extension the entire hedgehog projector.

Spin-Stabilized Rocket: A rocket stabilized by rotation about its long axis.

Spiral Scan: An r-f beam which traces out a special pattern that is caused by the wobbling motion of the antenna about its axis. It is used for search and acquisition.

Spot: Correction to be applied to gun position in order to hit target.

Spot Pyramiding: Application of a new spot before effect of a previous spot has had time to become apparent.

Spotter: An observer who reports the results of naval gunfire to the firing agency and who also may designate targets.

Spotting: The estimation of the required correction of range, elevation, deflection, and fuze range to hit the target. The Spotter is the person actually observing the fall of shot or burst and making the estimates of required corrections. A Spot is the correction estimated by the Spotter.

A. Spotting is classified as to Means by the station from which the observation is made:
   1. Ship Spot indicates that the spotter is stationed in the firing ship at a designated spotting station.
   2. Local Spot indicates that the spotter is stationed in the firing ship at or adjacent to a mount or turret.
   3. Shore Spot indicates that the spotter is stationed ashore.
   4. Air Spot indicates that the spotter is stationed in an aircraft or airship.

B. Spotting is classified as to Type by the manner in which observations are made:
   1. Visual:
      a. Eye Spotting is the term used to indicate observations made by eye without the use of optical instruments.

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b. Optical Spotting is the term used to indicate that observation is assisted by optical aids, including ordinary binoculars, spotting binoculars fitted with mil scales, spotting glasses, or stereoscopic range finders.

2. Radar:

a. Radar Spotting is the term used to indicate that the observation is made by radar.

C. Spotting is classified as to Method by the manner of estimating the error of burst or impact.

1. Direct Spotting is that method in which the spotter's correction is based on his estimate of the error of the mean point of impact from the target. A direct spot may be made on the fall of shot of one salvo or as the result of an observation of an initial ladder.

2. Bracket and Halving is a method used in visual spotting at extremely long ranges, from low spotting stations, or with poor illumination, when the spotter can determine whether the shots are short or over, but the amount of error cannot be estimated with reasonable accuracy. On observing the initial fall of shot, a spot is made which is believed to be sufficiently large to ensure crossing the target. If the next salvo crosses the target, the following spot is applied in the opposite direction (towards the target) but is half the amount of the initial spot. Successive spots are in the same direction until the target is crossed again. When this occurs, the direction of the spots is again reversed and again halved. The process is continued until the target is located within the pattern.

Squirrel-Cage Motor: A type of a-c induction motor with a cage-like conductor arrangement in the rotor.

SS: Illuminating projectile (Star Shell).

Stabilization Computer: A device that develops pitch and roll corrections for the UFCS.

Stabilization: The technique of correcting for deck inclination.

Stabilizing Generator: (See Damping generator.)

Stable Element: Gyroscopic device which maintains a reference horizontal plane. Related similar device for similar purpose is called "stable vertical."

Stack: Sonar unit for producing transmitted pulse and reproducing echo.

Stand: Foundation of gun mount or missile launcher. Incorporates training circle, and is secured to ship structure.

Standard Navy Maintenance Managment System: A plan of action to improve the management of maintenance and material resources in support of the Operating Forces of the Navy.

Star Gage: Instrument for measuring wear in gun bore.

Star Shell: (See Illuminating Projectile.)

Stator: A stationary part in or about which another part (the rotor) revolves, such as the stationary member of an electrical machine.

Stave: A group of magneticostrictive transducer elements arranged parallel to the long axis of a sonar transducer.

Sterilizing Device (SD): A device that automatically deactivates a mine firing system when a selected time has elapsed after planting.

Stereoscopic Rangefinder: An optical rangefinder using stereoscopic vision as its principle.

Straddle: This is obtained from a salvo in range (or deflection) when, excluding wild shots, a portion of the shots of that salvo fall or detonate short and other shots of the salvo beyond the target (right and left, respectively, for deflection). (In naval gunfire support this may be known as a Bracketing Salvo.)

Striker: A nonrated man training for a rating.

Subroc: SUBmarine ROCket. Submerged, submarine-launched, surface-to-surface rocket with nuclear depth charge or homing torpedo payload, primarily anti-submarine.

Subsonics: Sounds below audible range.

Superelevation: The angle the gun must be elevated above the line of sight to compensate for the curvature of the trajectory caused by the force of gravity acting on the projectile.

Superheater (Torpedo): (See Combustion Flask)

Supervisory Control: The direction of the overall employment of the ship's armament. It is concerned with the disposition of the batteries to best meet existing conditions, the interior communications plan to be used, the selection and designation of targets for batteries or groups thereof, and the designation

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of standard procedure to be employed. Supervisory control is exercised by the Weapons Officer, assisted by his Battery Officers, and by CIC Liaison Officers.

Support Fire: Fire directed by ships or other afloat units at targets ashore, usually in support of ground troops operations.

Surface Burst: An explosion of a nuclear bomb or projectile at the surface of the earth; also the explosion of a nuclear weapon at an elevation above ground such that the fireball touches the ground.

Suspension Lug: A lug used for supporting a bomb in its aircraft.

Swim-Out: An alternate method of launching torpedoes, in which the torpedo propels itself out of an underwater tube instead of being ejected.

Sympathetic Explosion: Detonation of an explosive mass by shock wave of another detonation in the vicinity.

Synchro: Any of five types of rotatable induction devices that can produce a unique voltage pattern corresponding to any shaft position, or reproduce the shaft position from the pattern, or control a servo to do this. They are used in data transmission systems and as computing devices.

Synchronous Motor: An a-c motor designed to operate "in step" with the a-c supply; hence it has a constant-speed characteristic limited in accuracy only by the steadiness of the supply frequency.

System Alignment: Adjustment of geometrical relationship between two or more major components of a weapon system.

Talos: A shipborne, surface-to-air missile with solid-propellant rocket/ramjet engine. It is equipped with a nuclear or nonnuclear warhead, and command, beam-rider homing guidance.

Target-Grid System: Method utilizing a grid spot converter device to make spots observed by ground parties available without delay to ship fire control systems.

Tartar: A shipborne, surface-to-air missile with solid-propellant rocket engine and nonnuclear warhead.

Tachometer Generator: A generator whose voltage output is directly and precisely proportional to its rate of rotation. Frequently used as a Damping Generator, (which see).

Tail (of Torpedo): Aftermost part of a torpedo. Carries propellers and control surfaces.

Talker: Enlisted man assigned to man a battle phone for an officer at a control station.

Tampion: Plug inserted in gun muzzle to protect bore.

Target Acquisition: The process of positioning the tracking apparatus of a control system so that a designated target is gated in the radar or fixed in the optics or open sights.

Target Angle: The relative bearing of own ship from the target, measured in the horizontal from the bow of the target clockwise from 0 degrees to 360 degrees.

Target Designation: The selection of the targets which are to be taken under fire, and transmission of the requisite information for acquisition to the selected fire control station or stations.

A. Target Designation is callified as to Type by the station originating the designation.
   1. Command Designation is the designation of a target by a command station.
      a. OTC designating a ship to take target under fire.
      b. CO of a ship designating target to be taken under fire.
   2. Control Designation is the designation of a target from a fire control station.
   3. Local Designation is the designation of a target by mount or turret personnel.

B. Target Designation is classified as to Method by the procedure employed for designation.
   1. Automatic Designation is the designation of the target by means of instruments which transmit sufficient data to the selected gun fire control system to result in target acquisition.
   2. Partial Automatic Designation is the designation of the target by means of a partially automatic system which must be aided by coaching in order that the selected director will be positioned to acquire the target.
   3. Verbal Designation is the designation of the target by voice or telephone.

Target Evaluation: Estimates of target intent, degree of threat, and type of attack to be delivered, based on plots of a target position.

Target Indication: A manifestation, to command and control, of targets approaching into or appearing in the area of gunfire. It includes

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all information available for proper designation, including the presence, identity, location, size, number, course, speed, and estimate of intent, plus any additional evaluated factors which are necessary for proper designation.

A. Target Indication is classified as to Type by the means by which target presence is manifested.
   1. Radar Indication describes manifestation of target presence by radar.
   2. Visual Indication describes manifestation of target presence by visual sighting.

B. Target Indication is classified as to Method by the system employed to display target presence.
   1. Automatic Indication is indication of targets by means of an electromechanical system capable of indicating in one display all targets appearing in the area under investigation.
   2. Manual Indication is the indication of targets by means of a manual plot of all targets observed or reported in the area under investigation.

Target (Projectile): (See BL.)

TCD (Sonar Display): Sonar display of PPI type using target as center.

TDS: Target Designation System.

TDT: Target Designation Transmitter.

Temperature Inversion (in Sea Water): A cooler layer of water overlying a warmer one.

Terrier: A surface-to-air missile with solid-fuel rocket motor. It is equipped with radar beam rider or homing guidance and nuclear or nonnuclear warhead.

Test Depth: Maximum depth for a submarine or underwater weapon.

Tetryl: An aniline-based organic compound used as a high explosive.

TH: (See Thermite.)

Thermite (or Thermate): A mixture of iron oxide and aluminum, often used as a filler in incendiary bombs.

Thermocline: Layer of sea water in which density changes rapidly with depth.

Theta (θ): Greek letter used to designate a selected angle.

Thrown Weapons: Small contact or proximity fuzed A/S explosive devices thrown by a rocket or mortar device from attacking surface ship.

Thyratron: A special type of high-output gas-filled electronic tube.

Time Base: Length of full-width sweep (A-scope radar presentation).

Time Fuze: A fuze which contains a graduated time element to regulate the time interval after which the fuze will function.

Time of Flight: Time elapsed from projectile's firing till its impact or explosion.

TNT: Trinitrotoluene. A high explosive.

Torch Pot: In a torpedo exercise head, the torch pot gives off smoke to assist the torpedo recovery crew to recover the torpedo at the end of a run.

Torpedo: A self-propelled underwater weapon whose explosive war head is detonated upon contact with or in proximity to a waterborne or subsurface target. A torpedo may be a component of a more complex weapon, for which it serves as the terminal stage. (Examples: Astor, Subroc, Dash.)

Torpedo Mines: (See Mobile mines.)

Torpedo Tube: A torpedo launching device tubular in configuration, from which the torpedo is normally ejected by compressed air.

Torque: Twisting effort, expressed in pound-feet.

Torque Motor: A motor whose armature movement is restricted to less than one revolution, and whose output is a torque proportional to its input.

Total Internal Reflection: (See Critical Angle.)

Tq: Underwater fire control symbol for dead time.

Tracer: Pyrotechnic device on projectile which shows projectile track when in flight.

Tracking: The process of establishing the path of target motion with respect to the firing ship; it is accomplished by combining the data obtained by the aiming and ranging processes.

A. Tracking is classified as to Type by the form of tracking employed.
   1. Direct Tracking is that type of tracking in which target path is established by direct observation (radar, optical or sonar).
   2. Indirect Tracking is that type of tracking in which the range, bearing, and elevation of the target are generated by the computer and its associated equipment.
   3. Offset Tracking is that type of tracking in which the target path is established by the direct observation of an intermediate point of aim in known relationship to the designated target.

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B. Tracking is classified as to Method by the manner in which the computers are employed to determine the path of target motion.
   1. Automatic Tracking is that method of tracking in which the target path is established by use of radar for aiming and ranging and without manual operation of any of the tracking controls in the fire control system.
   2. Automatic Lead Computing is that method of tracking in which the process of aiming automatically generates a solution of target motion. This method of tracking is associated with instruments using gyros to measure the angular velocity of the LOS.
   3. Rate Control is that method of tracking in which the computer's generated path of estimated target motion is made to coincide with the observed path of target motion by comparing the observed and generated rates of motion.
      a. Automatic Rate Control is that method of rate controlling in which the generated target motion is automatically corrected to agree with the observed target motion by a rate-control mechanism operated by the director operators.
      b. Semiautomatic Rate Control is that method of rate controlling in which the generated target motion is automatically corrected to agree with the observed target motion by a rate control mechanism operated by the computer operators.
      c. Manual Rate Control is that method of rate controlling in which the generated target motion is corrected to agree with observed target motion by changes to target course, speed, and angle of climb introduced manually by the computer operators.

Train: The movement in the horizontal plane of a gun mount or launching equipment.

Train Alignment: Alignment of fire control and weapon systems elements so that they are in effect all parallel and all at exactly the same angle to a selected vertical plan.

Trainer: One who moves a weapon in azimuth.

Training Circle: A large circular gear at the base of trainable weapon equipment.

Training Gear: Mechanical, electrical, and hydraulic equipment used to move weapon equipment in azimuth.

Tramming: Procedure for verifying train and elevation dial accuracy on gun mounts.

Transducer (Sonar): Device that translates sound waves into electrical signals, and vice versa.

Transmission Check: In fire control system alignment, the process of verifying that the data transmission system is functioning with the accuracy required.

Transmission Loss: Signal strength lost in transmission.

Transverse Waves: Vibration at right angles to direction of wave front movement.

Traverse Plane: A plane determined by a point of aim and the elevation axis of the sight.

Trench-Warfare Ammunition: Ammunition for certain types of infantry weapons.

Triple-Based Powder: (See Multi-based powder.)

Tilt Box: A part of an axial-piston pump containing the socket ring.

Tritonal: A mixture of TNT and aluminum powder.

True Target Bearing: True bearing of the target from the firing ship.

True Wind: Wind as it exists with respect to the earth and independent of any motion of the ship.

Trunnions: Part of the gun mount slide. The center of rotation in elevation movement.

Trunnion Tilt: Instantaneous inclination of the axis of the trunnions to the horizontal.

Tud: In underwater fire control, symbol for time to fire.

UB Plot: Underwater Battery Plot.

UFCS: Underwater Fire Control System.

Ultrasonics: Sound above normal human audible frequency range. Usual upper limit of audibility is taken to be about 15 KC (15,000 cps) ("Supersonics" used in this sense is no longer correct).

Underwater Demolition: The destruction or neutralization of underwater obstacles; this is normally accomplished by underwater demolition teams.

Unit Replacement Principle: Replacement of complete subassemblies by others in event of failure in the field, instead of replacement of failed or defective components only.

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Universal Motor: A motor (usually fractional horsepower) that can be operated on either a-c or d-c.

Upper Carriage: The part of the gun mount rotating structure that contains the trunnion bearings.

UPS: Universal Polar Stereographic (military grid system).

Urgent Attack (A/S): Attack on submarine which is in position to fire torpedoes.

USNMI: U.S. Navy Maneuvering Instructions.

UTM: Universal Transverse Mercator (military grid system).

Variable Time Fuze: A fuze designed to detonate a projectile, bomb, mine, or depth charge when activated by external influence other than contact in the close vicinity of a target.

VDS: Variable Depth Sonar. A device on the fantail of a destroyer to lower a sonar transducer to a variable depth to search below the layer depth.

Vehicle: The carrier or delivery device in a weapon system.

Vertical Plane: A plane perpendicular to the horizontal. It may pass through any designated line or point.

Very Light: A projected pyrotechnic device.

Vesicant: A chemical agent that blisters the skin, such as lewisite and mustard.

Video: Visual signal presentation, or electrical signal which eventually forms a part of a video presentation.

Virtual Image: An optical image that does not actually exist at the location where it appears to be.

VT: Proximity (fuze).

Wander Marks: Reticle marks used in stereoscopic rangefinder.

Warhead: 1. That part of a missile, projectile, or torpedo that constitutes the explosive, chemical, or other charge intended to damage the enemy. 2. A major assembly, which includes either the nuclear or thermonuclear system, high explosive system, chemical and biological agents or inert materials.

Warhead Section: A completely assembled warhead including appropriate skin sections and related components.

Watch, Quarter, and Station Bill (WQ & S Bill): A chart showing for each billet the name and rate assigned, cleaning and maintenance station, and assignments in condition watches and specific bills.

Waveguide: Radar wave conductor.

Weapon: The destructive unit in a weapon system. Except for guns, the weapon is the unit that actually destroys the target (commonly by explosion).

Weapon Alfa: A 12.75" rocket-propelled depth charge with a range of about 1000 yards.

Weapon System: The combination of a weapon (or multiple of weapons) and the equipment used to bring the destructive power of the weapon against the enemy. (NWP 10(A)) It includes units to—

1. Detect, locate, identify the target.
2. Deliver or start delivery of weapon to target.
3. Control delivery unit or weapon.
4. Destroy the target (weapons).

Weapons Doctrine: General instructions on course of action to be taken by officers supervising weapon operations in specific tactical situations.

Wear Gage: Instrument for measuring erosion at origin of rifling in minor caliber guns.

Weight: Amount of gravitational pull on a body.

Wild Shot: A shot with an abnormally large dispersion in range, or in deflection, or in both.

Wind Direction: Direction from which the wind is blowing.

Window: Projectile that ejects foil strips to make a deceptive radar target or screen.

Windshield: Thin metal fairing over nose of AP projectile.

WLO: Weapons Liaison Officer. The weapons department representative in CIC.

Work: Force acting against a resistance through a distance, resulting in movement of a load against a resistance, or acceleration of a mass.

Working Pressure Air: In a torpedo, compressed air at a pressure around 500 psi.

WP: White phosphorus.

Yoke (Gun): In bag guns, the equivalent of the gun housing.

Zero Length Rocket Launcher: A rocket launcher (used today only in aircraft) which does not support the rocket after the burning propellant has begun to move the rocket.

Zone of Responsibility: A predetermined area of enemy terrain which supporting ships are responsible for covering by fire on known targets or targets of opportunity and by observation.

Zuni: An air-to-surface unguided rocket with solid propellant. Can be armed with various types of heads, including flares, fragmentation, and armor piercing.

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Part 2. Glossary of Fire Control Symbols

Introduction. This is a special glossary designed for the convenience of those desiring to understand the derivation of fire control symbols or to know the meaning of specific symbols used in AA and surface gunnery. It does not cover symbols used in underwater fire control or in guided missiles fire control. For detailed authoritative treatment, the student is referred to OP 1700, which in its three volumes explains all fire control values, their symbols, and their derivation.

Method of forming symbols. Symbols are used in fire control to provide a concise, precise way to represent values which otherwise would require extended definition. Fire control symbols are made up of capital letters standing for basic quantities, and lower case letters, arabic numerals, the Greek letter Δ, and the prime (') used as modifying symbols. For example, *So* is made up of a basic symbol *S* meaning "speed," and a modifying symbol *o* meaning "of own ship." Hence the symbol *So* signifies own ship speed.

To illustrate the use of the prime, *B* is the basic symbol for bearing. Unmodified, it means true bearing, measured from a vertical plane through the north-south axis to a vertical plane through the line of sight to the target. The measurement is made in the horizontal plane, clockwise from north. *Br*, relative target bearing, is measured from a vertical plane through the fore-and-aft axis of own ship to a vertical plane through the line of sight. The measurement is made in the horizontal plane, clockwise from the bow of own ship. Since guns and directors are fastened to the deck of the ship, they can measure *Br* only at that instant when the deck is horizontal. Consequently, actual values of director train (an angle measured in the deck plane is called, in fire control language, *train*, not *bearing*) include a prime (') signifying that the quantity is measured with respect to the standard reference plane of the ship, or deck plane. *B'r*, director train, is the quantity actually used in some dual-purpose fire control systems, and is the angle measured from the vertical plane through the line of sight, in the deck plane clockwise from the bow of own ship. This measurement is possible only in systems which have stabilization of the director optics, so that the cross-wires of the telescopes are maintained in the vertical and horizontal. If this is not the case, director train is measured with respect to director sights which elevate in a plane perpendicular to the deck, and the symbol is *B'r'*, the first prime indicating "perpendicular to the deck plane." In the same way, *E* is elevation measured in a vertical plane and *E'* is elevation measured in a plane perpendicular to the deck.

Basic symbols and definitions

Symbol	Definition
A	Target angle.
B	Bearing (of target, unless modified) measured in the horizontal plane.
C	Course, measured in the horizontal plane.
D	Lateral deflection (angular measure).
E	Elevation (of target, unless modified) measured in the vertical plane.
F	Fuze setting.
G	Gyro angle (torpedoes).
H	Height of target (normally in feet).
I	Angle of climb or dive (inclination).
K	(Also *K1*, *K2*, etc.) Constants.
L	Level angle, measured in the vertical plane.
M	Roll.
N	Pitch.
P	Parallax.
Q	Spread gyro angle (torpedoes).
R	Range.
S	Speed.
T	Time.
U	Average projectile velocity.
V	Elevation prediction. (Angular measure.)
W	Wind.
X	Horizontal deflection component of velocity perpendicular to the vertical plane through the line of sight.
Y	Horizontal range component of velocity in the vertical plane through the line of sight.
Z	Crosslevel angle.

Common modifying symbols and definitions

Symbol	Definition
a	Of torpedo.
b	Of director.
c	Before a quantity means the value of that quantity as generated by the mechanism, as opposed to the observed value of the same quantity. After a quantity, *c* means relative to rate control.
d	Before a quantity means a time rate of change of that quantity. After a quantity, *d* means in or relative to the deck plane or plane perpendicular to the deck.

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Symbol	*Definition*
e	Elevation.
f	Due to standard trajectory.
g	Of gun.
h	Horizontal projection of.
j	Before a quantity means a correction or partial correction to that quantity, usually generated by the mechanism. After a quantity, *j* means arbitrary correction (spot) to that quantity.
m	Change of initial velocity.
o	Own ship; of or due to.
p	Parallax; of or due to.
q	Relative to the line of sound (ASW term).
r	Relative to own ship.
s	Relative to the line of sight, or in a slant plane. (Since several slant planes may be used, each definition specifies the plane used.)
t	Of or due to target.
u	Of torpedo tube.
v	Vertical projection of.
w	Of or due to wind.
z	Of or due to crosslevel.
f ( )	Function of the quantity in parentheses.
Δ (delta)	Before a quantity means change in that quantity during some specific time. Increment of a quantity.
----------	Indicates that a quantity is measured in or with respect to the deck plane.
2	After a quantity indicates that it is the predicted value of that quantity for advance position, i.e., for the position at time of flight seconds after firing, or at time of impact or burst.
3	After a quantity indicates that it is the predicted value of that quantity for the time of the burst, of a fuzed projectile, the fuze having been set dead time seconds before firing.

NOTE: In definitions when the terms "deck plane" or "plane of the deck" are used, the standard reference plane of the ship is meant.

Principal fire control quantities. (Selected items only are listed.)

A	Target angle. The angle between a vertical plane through the direction of target motion and the vertical plane through line of sight, measured in the horizontal plane clockwise from the direction of target motion.
B	True target bearing. The angle between a north- and south-vertical plane and the vertical plane through the line of sight, measured in a horizontal plane clockwise from the north.
B'gr	Gun train order. The ordered angle between the fore-and-aft axis of own ship and a plane through the gun axis perpendicular to the deck plane, measured in the deck plane clockwise from the bow of own ship, without parallax correction.
Br	Relative target bearing. The angle between the vertical plane through the fore-and-aft axis of own ship and the vertical plane through the line of sight, measured in a horizontal plane clockwise from the bow of own ship.
B'r	Director train (stabilized sight). The angle between the vertical plane through the fore-and-aft axis of own ship and the vertical plane through the line of sight, measured in the deck plane clockwise from the bow of own ship.
B'r'	Director train (sight not stabilized). The angle between the fore-and-aft axis of own ship and the plane through the line of sight perpendicular to the deck plane, measured in the deck plane clockwise from the bow of own ship.
Bw	True direction true wind. The angle between north and the direction from which the true wind is blowing, measured in a horizontal plane clockwise from north.
Co	Own-ship course. The angle between the north- and south-vertical plane and the vertical plane through the fore-and-aft axis of own ship, measured in a horizontal plane clockwise from north.
Ct	Target course. The angle between the north-and-south vertical plane and the vertical plane through the direction of motion of the target, measured in a horizontal plane clockwise from north.
cB	Generated true target bearing. (See definition of *B*.)
Δ*cB*	Increments of generated true target bearing.
cBr	Generated relative target bearing. (See *Br*.)
Δ*cBr*	Increments of generated relative target bearing.
cB'r	Generated director train (stabilized sight). (See *B'r*.)
Δ*cB'r*	Increments of generated director train (stabilized sight).
cB'r'	Generated director train (sight not stabilized). (See *B'r'*.)
Δ*cB'r'*	Increments of generated director train (Bearing correction).

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Symbol	Definition
cE	Generated target elevation. (See *E*.)
ΔcE	Increments of generated target elevation.
ΔcEb	Increments of generated director elevation $\Delta cEb = \Delta cE + L$.
cR	Generated present range.
ΔcR	Increments of generated present range.
Dd	Deck deflection (stabilized sight). The angle representing total deflection in the deck plane; it is added to director train to obtain gun train order, $B'gr$. $Dd + B'r = B'gr$ and $Dd = jDd + Dz$.
Dd'	Deck deflection (sight not stabilized). Angle representing total deflection in deck plane; it is added to director train to obtain gun train order, $B'gr$. $Dd' = Ds + Dz$.
Df	Drift correction. Deflection to compensate for drift of projectile, measured in the horizontal plane.
Dj	Deflection spot.
Ds	Sight deflection. Computed angle between vertical plane through line of sight and vertical plane through gun axis (neglecting parallax), measured in the horizontal or slant plane depending on system used.
Dz	Trunnion tilt train correction. Approximate correction in gun train order to compensate for tilting of gun trunnions in crosslevel.
dBr	Angular bearing rate. In the horizontal plane. The time rate of change of relative target bearing.
dBs	Angular bearing rate in slant plane. The time rate of change of target bearing measured in the slant plane through the line of sight.
dE	Angular elevation rate. The time rate of change of target elevation.
dR	Range rate. The time rate of change of range.
dRh	Horizontal range rate. The time rate of change of horizontal range.
E	Target elevation (stabilized sight). The angle between the horizontal plane and the line of sight, measured in the vertical plane through the line of sight. $E = Eb - L$.
E'	Target elevation (sight not stabilized). The elevation above the horizontal of the line of sight, measured in the plane perpendicular to the deck, through the line of sight.
Eb	Director elevation (stabilized sight). The elevation of the director line of sight above the deck, measured in the vertical plane through the line of sight.
E'b	Director elevation (sight not stabilized). The elevation of the director line of sight above the deck, measured in a plane perpendicular to the deck, through the line of sight.
Eg	Vertical gun elevation. The elevation of the gun above the horizontal, measured in a vertical plane through the gun axis.
E'g	Gun elevation order. Ordered elevation of the gun above the deck plane, measured in a plane through the gun axis perpendicular to the deck plane.
F	Fuze setting order. Fuze setting in seconds.
H	Target height. Vertical distance between the target and the horizontal plane through the director sights.
jB	Initial or corrective setting of generated target bearing.
jE	Initial or corrective setting of generated target elevation.
L	Level angle. The angle between the horizontal plane and the deck plane, measured in the vertical plane through the line of sight about an axis in the horizontal plane. (Positive when the deck toward the target is below the horizontal plane.)
L'	Level angle. The angle between the horizontal plane and the deck plane measured in the plane perpendicular to the deck through the line of sight about an axis in the deck. (Positive when the deck toward the target is below the horizontal plane.)
M	Roll. The instantaneous value of the angle between the reference plane and the horizontal, measured in an athwartship vertical plane.
N	Pitch. The instantaneous value of the angle between the reference plane and the horizontal, measured in a fore-and-aft vertical plane.
Pe	Elevation parallax correction for vertical base. (A different correction is made in main-battery systems.)
Ph	Train parallax correction for horizontal base.
R	Observed present range.
RdBs	Linear deflection (bearing) rate. The horizontal component of relative motion between target and own ship, at right angles to the vertical plane through the line of sight.
RdE	Linear elevation rate. The component of relative motion between target and own ship, at right angles to the line of sight and in the vertical plane through the line of sight.

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Symbol	*Definition*
Rh	Horizontal range. The projection of the range on a horizontal plane.
Rj	Range spot.
Rm	Range prediction to compensate for changes in I.V.
Rt	Range prediction to compensate for relative motion of own ship and target.
Rtg	Correction in fuze range for dead time.
R2	Advance range (or predicted range).
R3	Fuze range. *R2-Rtg*.
S	Target speed. (Note: For an air target this represents the speed of an air target along a line of flight with respect to the earth.)
So	Own ship speed. The speed of own ship relative to the earth.
Sw	True wind speed. The horizontal velocity of wind with respect to the earth.
T	Time. Generated by the regulated time motor on the computer.
Tf	Time of flight.
Tg	Dead time. Time in seconds between the setting of the fuze and the firing of the projectile.
V	Total elevation prediction. The approximate amount that target elevation changes during the time of flight. $V = Vtw - Vx + Vj$.
Vf	Superelevation. The angle the gun must be elevated above the predicted line of sight to compensate for the curvature of trajectory in the vertical plane.
Vfm	Correction to superelevation for a change in I.V.
Vj	Elevation spot.
Vs	Sight angle. The angle, computed in a vertical plane, which the gun must usually be elevated above the line of sight or the horizontal (depending on the system) in order to hit the target when the deck is horizontal. (A correction to *Vs* is needed to hit the target when the trunnions are tilted.)
Vt	Relative motion elevation prediction. Compensates for the relative motion of own ship and target during the time of flight.
Vw	Wind elevation prediction. Compensates for the effect of apparent wind on the projectile.
Vx	Complementary error correction. Correction to elevation prediction to compensate for deflection prediction.
Vz	Trunnion tilt elevation correction. Correction to gun elevation to compensate for the effect of crosslevel.
Zd	Crosslevel angle. Crosslevel angle measured about an axis in the deck; the angle, measured about the intersection of the plane of the deck with the vertical plane through the line of sight, between the vertical plane and a plane perpendicular to the deck through this axis. (Positive if when you face the target the right-hand side of the ship is up.)
Zdj	Selected crosslevel angle. Any arbitrary value of crosslevel when crosslevel is measured as indicated in the main symbol.
Zh	Crosslevel angle. Crosslevel angle measured about an axis in the horizontal; the angle, measured about the intersection of the horizontal plane with the vertical plane through the line of sight, between the vertical plane and a plane perpendicular to the deck through this axis. (Positive if when you face the target the right-hand side of the ship is up.)
Zhj	Selected crosslevel angle. Any arbitrary value of crosslevel when crosslevel is measured as indicated in the main symbol.

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APPENDIX B

BALLISTIC CALCULATIONS

Part 1: Uses of Range Tables

B1. INTRODUCTION

The range table published by the Bureau of Naval Weapons for each gun and for each projectile type fired by the gun presents, in convenient form, the elements of the trajectories resulting from firing that specified projectile, at a specified initial velocity, at various angles of elevation, under standard conditions. A range table tabulates, for each 100-yard increment of range, such characteristics of the trajectory as angle of elevation, time of flight, angle of fall, and striking velocity.

Preparation of a range table involves experimental firings of a number of the specified projectiles to obtain data used in conjunction with a complex set of equations or formulas to solve the trajectory.

Normal practice at the Naval Weapons Laboratory is to compute all range table entries directly from equations by means of large mechanical and electronic computing machines. These machines are capable of handling a large number of complex solutions rapidly and accurately.

B2. STANDARD CONDITIONS FOR RANGE TABLES

In the computations upon which range tables are based, certain arbitrary conditions are assumed. These are range-table standard conditions. To use the range table under conditions other than standard, it is necessary to provide in the table corrections for variations from these conditions.

The standard conditions assumed for range-table values are that:

1. The projectile leaves the gun with the designed velocity.
2. The projectile is of the designed weight.
3. The atmosphere is of an arbitrarily chosen standard density.
4. There is no wind.
5. The gun is motionless.
6. The target is motionless.[1]
7. The earth is motionless.
8. The gun and target are in the same horizontal plane, the plane tangent to the earth's surface at the gun.
9. The gun is elevated in the vertical plane; that is, the axis of the gun trunnions is horizontal at the time of firing.

Variations from any one of these conditions may cause a significant error. Therefore, in addition to the tabulation of trajectories under standard conditions, the range table provides necessary corrections for variations from the first six of these standard conditions. Corrections for variations from any of the last three require separate consideration or computation.

Correction for rotation of the earth can be computed from auxiliary tables published with range tables for major-caliber guns, or by fire control instruments. The amount and direction of the error vary with the azimuth of the line of fire, the latitude, and the range; but remain small in all cases. The correction is disregarded for guns of 5-inch caliber or smaller. The correction for tilt of the trunnion axis from the horizontal is practical only when using a mechanical solution and is considered in the fire control problem. Use of the columns of the range table to account for nonstandard conditions will be taken up later.

B3. A TYPICAL RANGE TABLE

The discussion which follows is based on the range table (OP551, third Revision) for the 5"/38 gun using a 55.18-pound AA common projectile. The table is based on an I.V. of

[1] Although motion of the target does not affect the trajectory itself, it enters into the problem of determining the trajectory that will reach the target.

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2500 ft. per sec., an average value for 5"/38 guns.

Columns 1 to 8 inclusive give values of elements of the trajectory under standard conditions corresponding to a given range, in increments of 100 yards.

Columns 10 to 18 inclusive (there is no column 9), list errors caused by the fact that actual firing is seldom if ever conducted under actual range table conditions. The heading over each column indicates both cause and direction of error.

B4. COLUMN 10

Column 10 is headed "Change in range for 10 F.S. increase in initial velocity.) The two major elements which affect initial velocity are gun erosion and variation in powder temperature. Of these, erosion causes a loss in initial velocity and a decrease in range. The Navy range tables are based on a standard powder temperature of 90° Fahrenheit. Magazine temperature rarely exceeds this figure. The variation in velocity due to temperature variation of one degree from 90° F. is stated in certain range tables and other Bureau of Weapons publications. The loss of initial velocity per degree of change of powder temperature will vary with the caliber, powder index (i.e., manufacturing lot), and erosion.

The loss of velocity caused by erosion is dependent upon the amount of bore enlargement. The range table includes one table which shows the amount of velocity loss for specified amounts of bore enlargement, which can be used following star gaging, and a second table showing bore enlargement versus equivalent service rounds fired, for use in periods between star gaging.

It must be noted that initial velocity for a new 5"/38 gun is 2600 ft per sec (often abbreviated also as f.s.). Since the average velocity during the life of the gun is 2500 ft per sec (the range table's assumed value), therefore, in a relatively new gun, velocity change due to bore enlargement may have to be computed in relation to the range table as a gain rather than a loss.

B5. COLUMN 11

Column 11 is headed "Change in range for 1 pound decrease in projectile weight." This change of range is due to two causes which are opposite in their effects. The first is the change in I.V. A projectile heavier than standard will be expelled from the gun at lower than designed I.V., causing a decrease in range. However, increase in weight will cause an increase in momentum, which results in an increase in range.

In practice, column 11 is not normally used aboard ship, since only projectiles of standard weight are fired. Projectiles are required to be of designed weight within small tolerances. The effects of these small variations are neglected. This small variation in projectile weight is one reason why all shots of a salvo, fired at the same time and under the same conditions, do not fall at the same point.

B6. COLUMN 12

Column 12 is headed "Change in range for 10 percent decrease in air density." For use under conditions where no aloft observations of air density are possible, a table has been prepared based on the results of many past observations aloft. The entering arguments are the height of the maximum ordinate in feet and the surface density; the result is the ballistic density. Standard surface density has been arbitrarily selected as the density of the atmosphere which results from a temperature of 59°F., a barometric pressure of 29.53 inches of mercury, and a humidity of 78 percent saturation. This standard surface density is assigned a numerical value of 1.000. To determine variation in the trajectory caused by variation from standard surface density, the temperature and barometric pressure are measured at the surface and the resulting density is expressed as a percentage of the standard. This percentage of standard density at the surface is then used in the table of ballistic density and from it the ballistic density is found.

B7. USE OF THE NOMOGRAM

The primary means of determining the change of range for variation of air density is by nomogram. The nomogram provided with the 5"/38 caliber range table is an example of the type in use in the Fleet today. When aloft aerological observations are not available, it gives a rapid solution of the error in range due to variation in atmospheric density. Instructions for its use are provided with the nomogram.

The use of the nomogram is more accurate than results obtained from using column 12 with surface observations, as it takes into account the ratio between mean measured and

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standard density for the actual maximum ordinate obtained.[2]

B8. COLUMNS 15 AND 18

Column 15 is headed "Change in range for 10 knot motion in plane of fire-target." and column 18 is headed "Deflection for—10 knot motion perpendicular to plane of fire-target." Actually, column 15 gives the distance that the target will move in the line of fire, if its speed in the line of fire is 10 knots, during the time of flight of the projectile. Column 18 given the same information for motion across the line of fire. The values in the columns are derived by multiplying the speed of 10 knots, expressed as 16.89/3 yards per second, by the time of flight of the projectile for the given range, as found in column 4 of the range table.

B9. COLUMNS 13 AND 16

Column 13 is headed "Change in range for 10 knot motion in plane of fire-wind." and column 16 is headed "Deflection for—10 knot motion perpendicular to plane of fire-wind."

A wind, or wind component, in the plane of fire, or line of fire, is spoken of as a range wind. A lateral wind (wind, or wind component, blowing across the line of fire) is spoken of as a cross wind.

The effect of a positive range wind (blowing in the direction in which the projectile is traveling) is to increase the range. The opposite is true for a negative range wind. A cross wind will carry the projectile in the direction toward which the wind is blowing.

The use of the columns is similar to that described in article B8.

B10. COLUMNS 14 AND 17

Column 14 is headed "Change in range for 10-knot motion in plane of fire-gun." and column 17 is headed "Deflection for 10-knot motion perpendicular to plane of fire-gun." By "motion of gun" is ment the "velocity imparted to the projectile due to motion of the firing ship," aside from the velocity imparted by the powder charge. This velocity may be positive or negative. Thus, a ship steaming at 10 knots and firing dead ahead imparts an added velocity of 16.89 ft per sec., in the horizontal plane. The same ship firing dead astern reduces the horizontal component of initial velocity by the same amount. Firing on the beam causes a velocity component across the line of fire in the direction of motion of the ship.

If no wind is blowing, a person standing on deck on a moving ship will feel an apparent wind, equal in force to the speed of the ship. It may therefore be said that a projectile fired from a moving ship, in still air, is opposed by an apparent wind equal in force but opposite in direction to the motion of the ship. The effect of such an opposing wind may be found in column 13 for range wind and in column 16 for cross wind.

The relation of columns 13 through 18 may best be understood from the following expression:

Column 14 = column 15—column 13, and
Column 17 = column 18—column 16.

Examination of any range table for any range shows that this relation is true. (The occasional difference of 2 or 3 yards is due to the fact that columns 14 and 17 actually are computed from formulas, the results plotted, and the curves faired.)

B11. DANGER SPACE AND HITTING SPACE

Column 7 of the range table is composed of values of the danger space (Chapter 8) for a target 20 feet high and of zero depth in the line of fire.

In the 5"/38 range table, range 10,000 yards, the danger space is 18 yards. The value of the danger space at this range for a target 30 feet high is 30/20 x 18 = 27 yards. Now if this 30-foot target has a beam of 105 feet (35 yards) it is apparent that its danger space is 27 + 35 = 62 yards. Column 19 of the range table, headed "Change in height of impact for variation of 100 yards in sight bar," is the column used for determining hitting space (Chapter 8). (Sight bar range is the range shown on the sight scale of the gun at the instant of firing.)

To find the hitting space for a 20-foot target at range 10,000 yards, see column 19. The value obtained is 112 feet; i.e., a variation in sight-bar range of 100 yards will move the point of impact 112 feet in the vertical plane of the target. To raise the point of

[2]Some recent range tables, including the one reproduced, have an additional column, 12a, which gives the change in range for a variation of temperature of the air of 10°F. from the standard air temperature. The effect given in column 12a is that caused by change in the elasticity of the air and is independent of and additional to the effect of any change in density. Column 12a is used with surface air temperature, the standard being taken as 59°F.

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impact 20 feet (to the top of the target) the sight-bar range would have to be increased $\frac{20}{112} \times 100 = 18$ yards.

This value for hitting space is the same as that earlier obtained for danger space. For most battle ranges this relationship holds; for the shorter ranges, however, there may be a considerable difference.

Column 19 is also used in the computation of the correction for trunnion height and curvature of the earth when figuring the initial ballistic correction. (See article B12.)

B12. DEFINITIONS OF VARIOUS BALLISTIC CORRECTIONS

For shipboard firings, it is necessary to determine, or to estimate, the variations from range-table standard conditions as they exist at the time of firing, and to compute corrections for the errors caused by these variations. The individual corrections are summarized and the result is called a ballistic correction.

Most of these ballistic corrections are automatically figured by the fire control computer from the initial inputs. However, there are some initial inputs that must be figured separately and set into the computer prior to firing. They are:

1. Arbitrary ballistic correction.
2. Correction for first salvo only.
3. Initial ballistic correction.

The arbitrary ballistic correction, also called arbitrary correction to hit or ACTH, is designed to correct for errors not otherwise accounted for. The correction is developed by exhaustive postfiring analysis of accurate data on ranges, target course and speed, and other elements in past gunnery practices. After all errors which can be accounted for (such as errors in rangefinder ranges and in estimates of target course and speed) have been eliminated in these analyses, there usually remains a certain amount of error in the point of fall for which no cause can be definitely assigned. When enough data have been obtained and analyzed to provide an accurate estimate of this quantity, it is used as an arbitrary ballistic correction.

The correction for first salvo only may be necessary if the initial round fired from a gun has a lower I.V., and therefore a shorter range, than succeeding rounds. This effect was at one time thought to be the result of the lower temperature of the bore; thus the correction has frequently and erroneously been known as "coldgun correction." It is now known that the loss of velocity is caused by oil in the bore; thus the correction is needed only if the bore has been cleaned and oiled since the last previous shot was fired. The amount of the correction is derived from experience, as is the ACTH, but it must be considered and treated separately, inasmuch as it is applied for the first salvo only and then removed. The first salvo correction should be used only if experience has shown it to be necessary.

Contemporary gun fire control systems develop automatically many of the inputs required for transmission to the gun mounts. However, there are several factors that must be estimated or figured with pencil and paper and introduced manually into the computer. These collectively constitute the initial ballistic correction. Exactly what goes into the initial ballistic correction depends on the particular fire control systems concerned. In most current types of gun fire systems the initial ballistic correction is inserted as three inputs—initial velocity (I.V.), initial range spot, and initial deflection spot. The next article enumerates the factors that go into the initial ballistic correction and explains how they are figured. Figure B1 shows a work sheet (filled in with fictitious values) for the computation of the initial ballistic correction. The work sheet shows which factors go respectively into the I.V. computation, the range correction (i.e., range spot) computation, and the deflection correction (spot) computation.

B13. COMPUTATION OF INITIAL BALLISTIC CORRECTION

In figure B1[3], the values are representative, but are not taken from an actual firing. The lines across the top of the sheet marked "Battery," "Exercise," etc., are for identification purposes.

B14. POWDER AND EROSION DATA

As item a in figure B1 enter the type powder, index number, and charge weight.

[3]The forms reproduced in figures B1 through B4 are marked CONFIDENTIAL when filled in with data pertaining to an actual gunnery practice, and must be so treated. In this case, however, the data used are purely hypothetical.

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CONFIDENTIAL
(When filled in)

WORKSHEET FOR THE COMPUTATION OF
THE INITIAL BALLISTIC CORRECTION

BATTERY	5/38	EXERCISE	SAMPLE	DATE FIRED	10 JAN. 1964
PROJECTILE	MK35-MK55 WT50	CHARGE	FULL	RANGE TABLE	OP551 (3rd REV.)

POWDER AND EROSION DATA

a	Powder Index SPDF CHARGE WT	15.8	c	Average Powder Temp.	80°F
b	I.V. Erosion Data	2600 FS	d	Temperature coefficient	1.2 FS/°F

e	Gun	PESR	Bore Enlargement Inches	Bore Enlargement Gauge	Powder Temp. Corr.	Velocity Loss F.S.	Erosion Corrector Setting F.S.
	1R	500	.078	43.4	0	5	NONE
	2R	520	.081	43.6	0	7	PROVIDED
	3R	530	.082	43.7	0	8	

ATMOSPHERIC CONDITIONS

f	Barometer	30.4"
g	Temperature	52°F
h	Ballistic Density	NOT OBTAINED

ROTATION OF EARTH

l	Latitude	NO CORRECTION
m	True Bearing	NEEDED FOR 5"

TRUNNION AND CURVATURE DATA

i	Average Trunnion Height	20.00 FT
j	Curvature of Earth	21.5 FT
k	Sum (i) + (j)	41.5 FT

RANGE TABLE DATA

A	Range	10,000
B	Column 12	493
C	Column 12a	11
D	Column 19	113
E	Column 11	-26

	COMPUTATION OF INITIAL VELOCITY	F.S.
1	Powder Temp., (d)x(90-c)	12
2	Erosion Lost and Index Correction	7
3	Total Velocity Loss, (1) + (2)	19
4	Item b	2600
5	Expected I.V. (4) - (3)	2581

	COMPUTATION OF RANGE CORRECTION	Yards Over	Yards Short
6	Air Density, (100-h)x(B) ÷ 10		210
7	Air Temperature, (59-g) x (C) ÷ 10	77	
8	Trunnion and Curvature, 100(k) ÷ (D)	37	
9	Rotation of Earth for (1), (m), and (A)		
10	Other range errors	21.3	
		Drop	Add
11	Sum, (6) through (10)		144
12	ACTH from previous practices		75
13	Correction for first salvo only		100
14	Total Correction (11) + (12) + (13)		319
	COMPUTATION OF DEFLECTION CORR.	Yards Right	Yards Left
15	Rotation of Earth for (1), (m), and (A)	x	x
16	Other deflection errors	x	x
		Mils Left	Mils Right
17	(1000) (15+16) ÷ (A)	x	x
18	ACTH from previous practices		5
19	Total Correction (17) + (18)		5

SAMPLE

92.3

Figure B-1.—Worksheet for the computation of initial ballistic corrections.

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In item b, enter the nominal velocity. Its value is found in the erosion-data section of the range table. It should be noted that this entry is not always the standard velocity used to compute the range table. In some cases, such as the 5"/38 range table, the expected average velocity of the gun's lifetime is used.

In item c, enter the average residual temperature of the powder to be fired.

In item d, "Temperature Coefficient," is obtained from the erosion-data section of the range table OP 551 (3rd revision); in this example, the temperature coefficient is 1.2.

Space is provided in item e for the erosion data of the individual guns. In this example the right gun of three 5-inch twin mounts is used. Entries are made for the gun munber, the "pseudo equivalent service rounds (PESR)", and bore enlargement or erosion-gage readings. The velocity loss due to erosion is determined by one of these values. When a gun is fired for the first time after star gage or bore erosion gage readings have been taken, the velocity loss is obtained directly from tables in the erosion data section of the range table. When star gage readings are available use the Velocity Loss vs. Bore Enlargement at Origin And Charge Weight Table (table. B1) for the type powder to be fired.

When bore erosion gage readings are available, use the velocity loss vs. erosion gage reading and charge weight for the type powder to be fired. This table is similar in construction to table B1.

Suppose, however, the ship has fired several times, since any erosion readings were taken on the gun barrel. In this event, the number of equivalent service rounds fired since the last star gage reading is determined. This number is added to the ESR determined with the star gage reading. This will give the best estimate of the present PESR. This value can then be used to obtain bore enlargement at the origin from table B2. With bore enlargement, table B1 can be entered to obtain velocity loss due to erosion.

If the powder temperatures vary more than 2° Fahrenheit (F) between guns, the powder temperatures are entered under the heading "Powder Temp. Corr." (fig. B1). The velocity loss for each gun is thus computed, using the formula in line 1 of the worksheet. If this is done, line 1 of the sheet is left blank. The velocity loss due to powder temperature is combined with the velocity loss due to bore enlargement. This sum is entered in the next column. The 5" /38 gun does not have an erosion corrector in its drive. Therefore, an average powder temperature is used in line 1 of the worksheet, and the average initial velocity loss (7 in this case) is used in line 2 of the worksheet.

B15. ATMOSPHERIC CONDITIONS

Item f is the barometer reading in inches, and item g is the temperature from the dry bulb thermometer in degrees Fahrenheit. Both are surface readings taken from the ship's instruments located in the ship's bridge. Item h, "Ballistic Density," is left blank unless this information is available.

B16. TRUNNION AND CURVATURE DATA

We will assume the exercise to be a surface firing with the stable element controlling elevation. Thus trunnion height and earth curvature corrections are necessary. Item i is the average height of the gun trunnions above the waterline. Item j is the earth's curvature for the range listed in (table B3.) Item k is the sum of items i and j.

B17. ROTATION OF THE EARTH

This correction is omitted for guns of 5-inch and below.

B18. RANGE TABLE DATA

The best estimate of firing range is entered as item A. Using this range, take items B, C, D, and E from the range table. (Appendix B, part 3).

B19. COMPUTATION OF INITIAL VELOCITY

Velocity loss should first be computed. Line 1 is the error in I.V. due to a variation in powder temperature from 90° F. It should be noted that if the temperature is greater than 90° F, the sign is negative (-), even though an increase in range results. The reason for this is not obvious, but a study of line 1 in comparison with lines 2 and 3 will clarify it. Line 2 is always a velocity loss (since erosion never increases I.V.). The effect of a powder temperature above 90° F will reduce this

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Table B-1.

VELOCITY LOSS vs BORE ENLARGEMENT AT ORIGIN & CHARGE WEIGHT

55.18 LB. PROJECTILE MKS. 35, 47 and 49

5"/38 CALIBER GUNS MK. 12 MOD. 1

SPDN SPDB SPD and SPDW INDEXES

NOMINAL VELOCITY 2600 f/s

BORE ENLARGEMENT AT ORIGIN (in thousandths of an inch)	CHARGE WEIGHT 14.4	14.6	14.8	15.0	15.2	15.4	15.6	15.8	16.0
0	-35	-35	-35	-35	-35	-35	-35	-35	-35
2	-37	-37	-37	-37	-37	-37	-37	-37	-37
4	-39	-39	-39	-39	-40	-40	-40	-40	-40
6	-40	-41	-41	-41	-42	-42	-42	-42	-43
8	-41	-42	-42	-42	-42	-43	-43	-43	-44
10	-41	-42	-42	-42	-42	-43	-43	-43	-44
12	-41	-42	-42	-42	-42	-43	-43	-43	-44
14	-41	-42	-42	-42	-42	-43	-43	-43	-44
16	-41	-42	-42	-42	-42	-43	-43	-43	-44
18	-40	-41	-41	-41	-42	-42	-42	-43	-43
20	-40	-40	-40	-40	-41	-41	-41	-42	-42
22	-39	-39	-39	-39	-40	-40	-40	-40	-40
24	-39	-39	-39	-39	-39	-39	-39	-39	-39
26	-37	-37	-37	-37	-38	-38	-38	-38	-38
28	-37	-37	-37	-37	-37	-37	-37	-37	-37
30	-35	-35	-35	-35	-35	-35	-35	-35	-35
32	-34	-34	-34	-34	-34	-34	-34	-34	-34
34	-33	-33	-32	-32	-32	-32	-32	-32	-32
36	-32	-32	-31	-31	-31	-31	-31	-31	-31
38	-30	-30	-30	-30	-29	-29	-29	-29	-28
40	-29	-28	-28	-28	-27	-27	-27	-27	-26
42	-27	-27	-26	-26	-25	-25	-25	-24	-24
44	-25	-25	-24	-24	-24	-23	-23	-22	-22
46	-24	-23	-23	-23	-22	-21	-20	-20	-19
48	-22	-22	-21	-20	-20	-19	-18	-17	-17
50	-21	-20	-19	-18	-18	-17	-16	-16	-15
52	-19	-18	-17	-17	-16	-15	-14	-13	-13
54	-17	-17	-16	-15	-14	-13	-12	-11	-10
56	-16	-15	-14	-13	-12	-11	-10	- 9	- 8
58	-14	-13	-12	-11	-10	- 9	- 8	- 7	- 6
60	-13	-11	-10	- 9	- 8	- 7	- 6	- 5	- 4
62	-11	-10	- 9	- 7	- 6	- 5	- 4	- 3	- 1
64	- 9	- 8	- 7	- 6	- 4	- 3	- 2	- 0	1
66	- 8	- 6	- 5	- 4	- 2	- 1	0	2	3
68	- 6	- 5	- 3	- 2	0	1	2	4	5
70	- 5	- 3	- 2	0	2	3	5	6	8
72	- 3	- 1	0	2	3	5	7	8	10
74	- 1	0	2	4	5	7	9	10	12
76	0	2	4	6	7	9	11	13	14
78	2	4	6	7	9	11	13	15	17
80	3	5	7	9	11	13	15	17	19
82	5	7	9	11	13	15	17	19	21
84	7	9	11	13	15	17	19	21	23
86	8	10	13	15	17	19	21	23	26
88	10	12	14	17	19	21	23	26	28
90	11	14	16	18	21	23	25	28	30
92	13	15	18	20	23	25	27	30	32
94	15	17	20	22	25	27	30	32	35
96	16	19	21	24	27	29	32	34	37
98	18	21	23	26	28	31	34	36	39
100	20	22	25	28	30	33	36	39	41
102	21	24	27	30	32	35	38	41	44
104	23	26	28	31	34	37	40	43	46
106	24	27	30	33	36	39	42	45	48
108	26	29	32	35	38	41	44	47	50

BORE ENLARGEMENT AT ORIGIN (in thousandths of an inch)	CHARGE WEIGHT 14.4	14.6	14.8	15.0	15.2	15.4	15.6	15.8	16.0
110	28	31	34	37	40	43	46	49	53
112	29	32	36	39	42	45	48	52	55
114	31	34	37	41	44	47	50	54	57
116	32	36	39	42	46	49	53	56	59
118	34	37	41	44	48	51	55	58	62
120	36	39	43	46	50	53	57	60	64
122	37	41	44	48	52	55	59	62	66
124	39	42	46	50	54	57	61	65	68
126	40	44	48	52	55	59	63	67	70
128	42	46	50	54	57	61	65	69	73
130	44	48	51	55	59	63	67	71	75
132	45	49	53	57	61	65	69	73	77
134	47	51	55	59	63	67	71	75	79
136	48	53	57	61	65	69	73	78	82
138	50	54	58	63	67	71	75	80	84
140	52	56	60	65	69	73	78	82	86
142	53	58	62	66	71	75	80	84	88
144	55	59	64	68	73	77	82	86	91
146	56	61	66	70	75	79	84	88	93
148	58	63	67	72	77	81	86	91	95
150	60	64	69	74	79	83	88	93	97
152	61	66	71	76	80	85	90	95	100
154	63	68	73	78	82	87	92	97	102
156	64	69	74	79	84	89	94	99	104
158	66	71	76	81	86	91	96	101	106
160	68	73	78	83	88	93	98	103	109
162	69	74	80	85	90	95	101	106	111
164	71	76	81	87	92	97	103	108	113
166	72	78	83	88	94	99	105	110	115
168	74	80	85	90	96	101	107	112	118
170	76	81	87	92	98	103	109	114	120
172	77	83	88	94	100	105	111	117	122
174	79	85	90	96	102	107	113	119	124
176	80	86	92	98	104	109	115	121	127
178	82	88	94	100	105	111	117	123	129
180	84	90	96	101	107	113	119	125	131
182	85	91	97	103	109	115	121	127	133
184	87	93	99	105	111	117	123	130	136
186	89	95	101	107	113	119	126	132	137
188	90	96	103	109	115	121	128	134	140
190	92	98	104	111	117	123	130	136	142
192	94	101	107	114	120	126	133	139	146
194	97	103	110	116	123	130	136	143	149
196	99	106	113	119	126	133	139	146	153
198	102	109	115	122	129	136	143	150	156
200	104	111	118	125	132	139	146	153	160
202	107	114	121	128	135	142	149	156	163
204	109	117	124	131	138	145	153	160	167
206	112	119	126	134	141	148	156	163	171
208	114	122	129	137	144	152	159	167	174
210	117	124	132	140	147	155	162	170	178

Submitted: E. Kuchner Captain, USN
Ordnance Officer

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Commander, Naval Proving Ground

U. S. Naval Proving Ground
Dahlgren, Virginia
May 1953

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Table B-2.

5"/38 CALIBER GUNS Mk. 12 Mod. 1

BORE ENLARGEMENT AT ORIGIN vs EQUIVALENT SERVICE ROUNDS

ESR	0	10	20	30	40	50	60	70	80	90
0	.000	.001	.001	.002	.002	.003	.004	.005	.006	.007
100	.008	.009	.011	.012	.013	.015	.016	.018	.020	.022
200	.024	.027	.029	.032	.035	.037	.040	.042	.044	.046
300	.048	.050	.052	.054	.055	.057	.059	.060	.062	.064
400	.065	.067	.068	.069	.071	.072	.073	.075	.076	.077
500	.078	.079	.081	.082	.083	.084	.085	.086	.087	.088
600	.089	.090	.091	.092	.093	.094	.095	.096	.096	.097
700	.098	.099	.100	.101	.101	.102	.103	.104	.105	.105
800	.106	.107	.108	.108	.109	.110	.110	.111	.112	.112
900	.113	.114	.114	.115	.116	.116	.117	.117	.118	.119
1000	.119	.120	.120	.121	.122	.122	.123	.123	.124	.124
1100	.125	.125	.126	.127	.127	.128	.128	.129	.129	.130
1200	.130	.131	.131	.132	.132	.133	.133	.133	.134	.134
1300	.135	.135	.136	.136	.137	.137	.138	.138	.138	.139
1400	.139	.140	.140	.140	.141	.141	.142	.142	.143	.143
1500	.143	.144	.144	.144	.145	.145	.146	.146	.146	.147
1600	.147	.147	.148	.148	.149	.149	.149	.150	.150	.150
1700	.151	.151	.151	.152	.152	.152	.153	.153	.153	.154
1800	.154	.154	.155	.155	.155	.156	.156	.156	.157	.157
1900	.157	.158	.158	.158	.159	.159	.159	.159	.160	.160
2000	.160	.161	.161	.161	.162	.162	.162	.162	.163	.163
2100	.163	.163	.164	.164	.164	.165	.165	.165	.165	.166
2200	.166	.166	.167	.167	.167	.167	.168	.168	.168	.168
2300	.169	.169	.169	.169	.170	.170	.170	.170	.171	.171
2400	.171	.171	.172	.172	.172	.172	.173	.173	.173	.173
2500	.174	.174	.174	.174	.174	.175	.175	.175	.175	.176
2600	.176	.176	.176	.177	.177	.177	.177	.177	.178	.178
2700	.178	.178	.179	.179	.179	.179	.179	.180	.180	.180
2800	.180	.180	.181	.181	.181	.181	.182	.182	.182	.182
2900	.182	.183	.183	.183	.183	.183	.184	.184	.184	.184
3000	.184	.185	.185	.185	.185	.185	.186	.186	.186	.186
3100	.186	.186	.187	.187	.187	.187	.187	.188	.188	.188
3200	.188	.188	.189	.189	.189	.189	.189	.189	.190	.190
3300	.190	.190	.190	.191	.191	.191	.191	.191	.191	.192
3400	.192	.192	.192	.192	.192	.193	.193	.193	.193	.193
3500	.193	.194	.194	.194	.194	.194	.194	.195	.195	.195
3600	.195	.195	.195	.196	.196	.196	.196	.196	.196	.197
3700	.197	.197	.197	.197	.197	.198	.198	.198	.198	.198
3800	.198	.198	.199	.199	.199	.199	.199	.199	.200	.200
3900	.200	.200	.200	.200	.200	.201	.201	.201	.201	.201
4000	.201	.202	.202	.202	.202	.202	.202	.202	.203	.203
4100	.203	.203	.203	.203	.203	.204	.204	.204	.204	.204
4200	.204	.204	.205	.205	.205	.205	.205	.205	.205	.206
4300	.206	.206	.206	.206	.206	.206	.206	.207	.207	.207
4400	.207	.207	.207	.207	.208	.208	.208	.208	.208	.208
4500	.208	.208	.209	.209	.209	.209	.209	.209	.209	.210
4600	.210	.210	.210	.210	.210	.210	.210	.211	.211	.211
4700	.211	.211	.211	.211	.211	.212	.212	.212	.212	.212
4800	.212	.212	.212	.213	.213	.213	.213	.213	.213	.213
4900	.213	.213	.214	.214	.214	.214	.214	.214	.214	.214
5000	.215	.215	.215	.215	.215	.215	.215	.215	.216	.216
5100	.216	.216	.216	.216	.216	.216	.216	.217	.217	.217
5200	.217	.217	.217	.217	.217	.217	.218	.218	.218	.218
5300	.218	.218	.218	.218	.218	.219	.219	.219	.219	.219
5400	.219	.219	.219	.219	.220	.220	.220	.220	.220	.220
5500	.220	.220	.220	.221	.221	.221	.221	.221	.221	.221
5600	.221	.221	.221	.222	.222	.222	.222	.222	.222	.222
5700	.222	.222	.223	.223	.223	.223	.223	.223	.223	.223
5800	.223	.223	.224	.224	.224	.224	.224	.224	.224	.224
5900	.224	.224	.225	.225	.225	.225	.225	.225	.225	.225

Bore Enlargement at Origin in inches

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Table B-3.

CURVATURE OF EARTH, FEET

R. yds.	0	100	200	300	400	500	600	700	800	900
1,000	0. 2	0. 3	0. 3	0. 4	0. 4	0. 5	0. 6	0. 6	0. 7	0. 8
2,000	. 9	. 9	1. 0	1. 1	1. 2	1. 3	1. 5	1. 6	1. 7	1. 8
3,000	1. 9	2. 1	2. 2	2. 3	2. 5	2. 6	2. 8	2. 9	3. 1	3. 3
4,000	3. 4	3. 6	3. 8	4. 0	4. 2	4. 4	4. 6	4. 8	5. 0	5. 2
5,000	5. 4	5. 6	5. 8	6. 1	6. 3	6. 5	6. 8	7. 0	7. 2	7. 5
6,000	7. 8	8. 0	8. 3	8. 5	8. 8	9. 1	9. 4	9. 7	10. 0	10. 3
7,000	10. 6	10. 9	11. 2	11. 5	11. 8	12. 1	12. 4	12. 8	13. 1	13. 4
8,000	13. 8	14. 1	14. 5	14. 8	15. 2	15. 6	15. 9	16. 3	16. 7	17. 1
9,000	17. 4	17. 8	18. 2	18. 6	19. 0	19. 4	19. 9	20. 3	20. 7	21. 1
10,000	21. 5	22	22	23	23	24	24	25	25	26
11,000	26	27	27	28	28	29	29	30	30	31
12,000	31	32	32	33	33	34	34	35	35	36
13,000	36	37	38	38	39	39	40	41	41	42
14,000	42	43	44	44	45	46	46	47	47	48
15,000	48	49	50	51	51	52	53	53	54	55
16,000	55	56	57	58	58	59	60	61	61	62
17,000	62	63	64	65	66	66	67	68	69	69
18,000	70	71	72	73	73	74	75	75	76	77
19,000	78	79	80	81	81	82	83	84	85	85
20,000	86	87	88	89	90	91	92	93	94	94
21,000	95	96	97	98	99	100	101	102	103	103
22,000	104	105	106	107	108	109	110	111	112	113
23,000	114	115	116	117	118	119	120	121	122	123
24,000	124	125	126	127	128	129	131	132	133	134
25,000	135	136	137	138	139	141	142	143	144	145
26,000	146	147	148	149	150	152	153	154	155	156
27,000	157	159	160	161	162	163	164	165	167	168
28,000	169	171	172	173	174	175	177	178	179	180
29,000	181	183	184	185	186	188	189	190	192	193
30,000	194	195	197	198	200	201	202	203	205	206
31,000	207	209	210	211	213	214	215	217	218	219
32,000	221	222	224	225	226	228	229	231	232	233
33,000	235	236	238	239	240	242	243	245	246	247
34,000	249	251	252	253	255	257	258	259	261	263
35,000	264	265	267	269	270	272	273	275	276	277
36,000	279	281	282	284	286	287	289	290	292	293
37,000	295	297	298	300	302	303	305	307	308	309
38,000	311	313	315	317	318	319	321	323	325	326
39,000	328	329	331	333	335	336	338	340	342	343
40,000	345	------	------	------	------	------	------	------	------	------
R. yds	0	100	200	300	400	500	600	700	800	900

110.125

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loss, while a powder temperature below 90° F will increase the loss. Line 3, which is the algebraic sum of lines 1 and 2, will therefore be of the correct sign if powder temperature correction is treated as described above. Should line 3 result in a minus sign, it would indicate a velocity gain. Such a case could occur with a new gun when firing powder from a magazine where the powder temperature was above 90° F. This will rarely happen.

Line 4 is the nominal velocity from item b. Line 5 is the expected I.V. which is found by subtracting the Total Velocity Loss (line 3) from the Nominal Velocity (line 4). This result (line 5) is the expected initial velocity of the projectile, and should be set into the computer.

B20. COMPUTATION OF RANGE CORRECTION

To begin with, the difference between the expected impact point for standard conditions and the expected impact point for existing conditions is dealt with. The entry in line 6 has been determined from the nomogram (appendix B, part 2) in the range table. When ballistic density (item h) is used, the formula in line 6 will give the proper value of range correction due to density. If item h is greater than 100%, the entry is made in the "Short" column; if less than 100%, the entry is made in the "Over" column. Line 7 is the range change due to variations of the air temperature from standard. If the air temperature is above standard, the entry is made in the Short column; if below standard, the entry is made in the Over column.

The trunnion height and curvature entry in line 8 is always "over." Column 19 of the range table gives the change in height of impact due to a 100-yard change in range. These values assume the gun and target are in the horizontal plane. Trunnion height and earth's curvature are the amounts the problem deviates from the horizontal plane. Since the problem is concerned with total deviation from the horizontal, these factors can be combined. The formula in line 8 results in the number of yards by which range must be changed to compensate for total deviation.

No compensation is made for earth's rotation in the 5"/38 battery. Therefore line 9 is left blank. Line 10, "Other Range Errors," is provided for range errors which are normally not encountered. Under this heading in the example is projectile weight. The range table is based on a projectile weight of 55.18 pounds, however the projectile in this example weighs 56 pounds. The formula used to calculate the compensation for the effect of a variation in projectile weight is shown in the table below.

Column 11 of the range table gives the effect on range due to a decrease in weight. Since in the example the projectile is heavier, range is increased. Projectiles heavier than standard will leave the gun at a lower initial velocity, which results in a decrease in range. The heavier projectiles however have an increase in ballistic coefficient which results in an increase in range. At short ranges the change in initial velocity has the greater effect, but at long ranges the ballistic coefficient has the greater effect.

Line 11 is the algebraic sum of the range errors. Note that the column headings have been changed from "Over" to "Drop," and from "Short" to "Add." In this manner the errors are converted to corrections. These are reciprocal quantities.

range table	weight	-	actual weight	x	column 11	=
55.18	-		56	x	-26	=
	.82			x	26	= 21.3

The Arbitrary Correction To Hit (ACTH) in line 12 and the correction for first salve only in line 13 are obtained from experience within the individual battery. The ACTH remains throughout the firing, but the value of line 13 is removed after the first salvo.

Line 14 is the algebraic sum of the range corrections. This value is set into the computer as a range spot. In AA fire the range correction is sometimes converted to an initial velocity correction. When this is done the first salvo correction is not included, and the trunnion height and earth curvature corrections are not needed. The formula to convert range correction to initial velocity correction is:

$$\frac{\text{Range correction} \times 10}{\text{Column 10}} = \text{Initial velocity correction}$$

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B21. COMPUTATION OF DEFLECTION CORRECTION

Line 15 indicates the error in deflection due to earth's rotation. As in the computation for range deflection, it is used only in batteries larger than 5-inch. The error's value and sign are obtained from the range table.

Line 16, "Other Deflection Errors," is provided for deflection errors which are normally not encountered.

The formula in line 17 is used to convert yards to mils. Deflection is normally spotted in mils. Note that the column headings have been changed from "Right" to "Left," and from "Left" to "Right." As in range, we are converting from the error to the correction. The ACTH in line 18 is obtained from previous gunnery exercise. Line 19 is the total deflection correction and is applied to the computer as a deflection spot.

B22. POSTFIRING ANALYSIS: GUNNERY SHEET 4

It has been said, "The best rangefinder is the gun." This implies that the effectiveness of a fire control system is shown by the actual impact point of the projectile. Postfiring analysis concerns itself with a comparison between the observed impact point and the correct theoretical position of the impact point. From this comparison, consistent errors which cannot be accounted for are determined. ACTH in range and deflection is computed from these errors. The most satisfactory results are obtained when error-producing factors (such as relative motion and initial ballistic calculation) are held to a minimum. The ACTH is normally computed from a particular gunnery exercise. This exercise, normally a Z-24-G, should be held under as nearly ideal conditions as possible. The battery should have been accurately aligned, and the fire control system should have been brought to peak performance.

Standard procedure and standard forms are used to determine the ACTH. The standard form is Gunnery Sheet #4 shown in figures B3 and B4. A worksheet (fig. B2) is used in conjunction with the finished smooth Sheet 4. Observers record the needed information available aboard ship for each salvo. The location of the impact point or mean point of impact (MPI) is obtained from a spotting or photographic party. Spotting procedures were covered in chapter 8.

Figures B3 and B4 show a sample problem of a salvo from the right guns of the twin 5" mounts of a destroyer battery. The values in the figures are representative but are not from an actual exercise.

B23. POSTFIRING ANALYSIS: PREPARATION OF WORKSHEET

A separate worksheet should be used for each salvo. The worksheet represents a complete picture of the conditions that existed at the instant the salvo was fired.

Range Table Data

In item A (fig. B2) enter the initial velocity for which the range table (Appx. B part 3) is computed. The 5" range table (OP 551 3rd Revision) is computed for 2500 foot-seconds.

In item B enter the gun's angle of elevation above the horizontal plane at the time of firing. When the stable element controls elevation, this value is obtained from sight angle. Since 2000 minutes represents zero sight angle, we have subtracted 2000 from the value of sight angle in the computer.

When the director controls elevation, sight angle is the angle between the LOS and the LOF. In this case trunnion height and earth curvature corrections are converted to minutes of arc and subtracted from sight angle. This brings the LOS into the horizontal plane. In batteries which have individual erosion correctors, the settings on the corrector affect gun elevation. The velocity loss in foot-seconds is converted to minutes of arc and subtracted from sight angle.

Item C is the range table value corresponding to item B. In the example, a range of 10,100 corresponds to an angle of elevation of 675.5 minutes above the horizontal plane.

Items D through N are taken directly from the range table, using the range in item C. The remainder of the worksheet is used to compute the initial velocity, range, and deflection problems of the exercise.

B24. POSTFIRING ANALYSIS: COMPUTATION OF ARBITRARY CORRECTION TO HIT (RANGE)

The first lines on Gunnery Sheet 4 (fig. B3) are for identification purposes and in general

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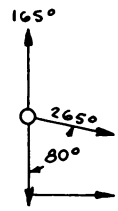
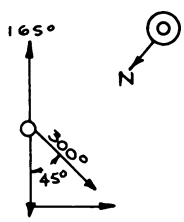
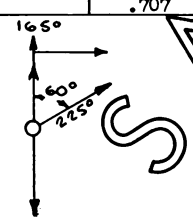
(When filled in)

WORKSHEET FOR PREPARING GUNNERY SHEET 4
(Use separate Worksheet for each Salvo)

Z	True Target Bearing At Instant of Firing	165°		RANGE TABLE DATA	
			A	Range Table I.V.	2500 F.S.
			B	Guns Elevation	675.5 Min.
			c	GUN Range (1)	10100 Yds.
			D	Column 10	47 Yds.
			E	Column 12	499 "
			F	Column 12a	10 "
			G	Column 13	84 "
			H	Column 14	43 "
			I	Column 15	127 "
	Target		J	Column 19	115 Ft.
AA	True Course	265°			
BB	Speed	20	K	Column 6 (2)	47.7 Yds
CC	Acute Angle	80°	L	Column 16	57 "
DD	Cosine	.174	M	Column 17	69.6 "
EE	Sine	.985	N	Column 18	126.6 "
				ATMOSPHERIC CONDITIONS	
			O	Barometer	30.40 In.
			P	Temperature	52° F
			Q	Ballistic Density	104.3 %
				POWDER AND EROSION DATA	
			R	I.V. (Erosion Data)	2600 F.S.
			S	Temperature Coefficient	1.2 F.S.°/F
			T	Average Powder Temperature	80° F
	Surface, Upper Air Wind		U	Bore Enlargement - Inches Gauge	.080
FF	True Course	300°			
GG	Velocity	10		TRUNNION AND CURVATURE DATA	
HH	Acute Angle	45°	V	Average Trunnion Height	20 Ft.
II	Cosine	.707	W	Curvature of Earth	21.5 Ft.
JJ	Sine	.707	X	Sum (V) + (W)	41.5 Ft.
				COMPUTATION OF INITIAL VELOCITY	F.S.
			1	Powder Temp. Correction (S) x (90-T)	12
			2	Erosion Loss & Index Correction	7
			3	Total Velocity Loss (1) + (2)	19
			4	Item R	2600
			5	Expected I.V. (4) - (3)	2581
			6	Item A	2500
			7	I.V. Difference (5) - (6)	81
	Own Ship			COMPUTATION IN RANGE	YARDS
KK	True Course	225°			
LL	Speed	18			
MM	Acute Angle	60°	8	I.V. Difference (7)x(D)+10 (3)	+381
NN	Cosine	.500	9	Own Ship Motion (LL)x(NN)x(H)+10 (4)	+39
OO	Sine	.866	10	Wind (GG)x(II)x(G)+10 (5)	-59
			11	Air Density (100-Q)x(E)+10 (6)	-200
(1)	Enter in Sheet 4 as item d		12	Air Temperature (59-P)x(F)+10 (7)	+7
(2)	Enter in Sheet 4 as item v		13	Trunnion and Curvature 100(y)+J (8)	+36
(3)	Enter in Sheet 4 as total for items k, l and m		14	Target Motion (BB)x(DD)x(I)+10 (9)	-44
				COMPUTATION IN DEFLECTION	YARDS
(4)	Enter in Sheet 4 as item e		15	Own Ship Motion (LL)x(OO)x(M)+10 (10)	+109
(5)	Enter in Sheet 4 as item f		16	Wind (GG)x(JJ)x(L)+10 (11)	+40
(6)	Enter in Sheet 4 as item g		17	Target Motion (100)x(BB)x(EE)x(N)+(P)+(14) (12)	+25
(7)	Enter in Sheet 4 as item h				
(8)	Enter in Sheet 4 as item j				
(9)	Enter in Sheet 4 as item q				
(10)	Enter in Sheet 4 as item w				
(11)	Enter in Sheet 4 as item x				
(12)	Enter in Sheet 4 as item bb				







SAMPLE

92.4

Figure B-2.—Worksheet for preparing Gunnery Sheet 4.

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GUNNERY SHEET 4
OPNAV FORM 3570-4 (Rev. 2-53)

CONFIDENTIAL
(When filled in)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (RANGE)

U.S.S	EXERCISE SAMPLE	RUN Projectile	DATE
BATTERY 5"/38	CHARGE (Full, reduced) Full	Range Table (Op No. 551 (3rd Rev.)	AND CHANGE NO.
POWDER INDEX SPDF WT 15.8	EROSION CURVES NPG NO.		AND

ITEM (Tabulate range and change in range in yards)	SALVO NO 1	SALVO NO	SALVO NO	SALVO NO	SALVO NO	SALVO NO	SALVO NO
a. Number of guns	3						
b. Number of cold guns	0						
c. Guns fired	1R,2R,3R						
d. Gun range	10100						
e. Own ship's motion	+39						
f. True wind (upper air, surface)	-59						
g. Air density (upper air, surface)	-200						
h. Air temperature	+7						
i. Rotation of earth	---						
j. Trunnion height and earth's curvature	+36						
k. Powder index							
l. Powder temperature	+381						
m. Erosion							
n. Sum of e through m	+204						
o. Expected range (d+n)	10304						
p. Naviagational range at instant of firing	9950						
q. Target motion	-44						
r. Error of MPI	+140						
s. Actual range (p + q + r)	10044						
t. ACTH in range (o-s)	+360						

NOTES: c. Identify guns by turret or mount number and gun position, i.e., IR; 2C; 3 all, etc.
d. Gun range is range table range corresponding to elevation of gun above horizontal plane.
e. Through m & q compute, using methods explained in range table, erosion curves & NAVPERS 16116, Naval Ordnance and Gunnery, page 271
f. & g. Cross out either upper air or surface as applicable.

SAMPLE

63.40

Figure B-3. —Gunnery Sheet 4—ACTH Range.

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GUNNERY SHEET 4
OPNAV FORM 3570-4 (Rev. 2-53) (BACK)

CONFIDENTIAL
(When filled in)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (DEFLECTION)

ITEM (Tabulation range and change in range in yards)	SALVO NO 1	SALVO NO	SALVO NO	SALVO NO	SALVO NO	SALVO NO	SALVO NO
u. Deflection used (mils)	+3						
v. Drift (yds.) (right)	+47.7						
w. Own ship's motion (yds.)	+109						
x. Wind (yds.)	+40						
y. Rotation of earth (yds.)	----						
z. 1000 (v.+w.+x.+y) ÷ s. (mils)	+20						
aa. Expected deflection MPI (u.+z.) (mils)	+23						
bb. Target motion (mils)	+25						
cc. Error of MPI (mils)	-2						
dd. Actual deflection MPI (bb+cc) (mils)	+23						
ee. ACTH in deflection (aa-dd) (mils)	0						

NOTES: v. through y and bb, refer to range table, erosion curves and NAVPERS 16116, Naval Ordnance & Gunnery

bb. is $\frac{\text{deviation for laterial motion of target (yds)}}{p + q}$

cc. is $\frac{\text{error of MPI from center of target (yds)}}{}$

SAMPLE

63.40

Figure B-4.—Gunnery Sheet 4—ACTH Deflection.

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are self-explanatory. However, the space labeled "RUN" is normally used to identify the projectile/fuze combination and the weight of the combination.

Item a, "Number of Guns," refers to the number of guns actually fired. If, for example, a 6-gun salvo was intended, but due to a casualty only five guns fired, the proper entry is 5.

In item b, "Number of Cold Guns," enter the number of guns firing their initial round since the barrel was last cleaned and oiled. It should be assumed that the guns were fired just previous to this exercise. Therefore the entry is zero.

Item c, "Guns Fired," identifies guns by turret or mount number and position in the turret or mount. The right guns of mounts 1, 2, and 3 were fired in this hypothetical practice.

Items d, e, f, g, h, and j are obtained from the worksheet. It is essential that the sign be carried with transfered values. Item i is zero in the example. (This correction is always omitted for guns of 5-inch and smaller caliber.)

The total for items k, l, and m is combined in the computations on the worksheet. Although the computed I.V. of 2581 foot-seconds would cause a decrease in range from the values taken from a 2600 foot-second range table, it does cause an increase in the range values taken from the 2500 foot-second range table which is being used in computing values in the example. Therefore, the sign is PLUS for this entry of 381 yards.

Item o, the expected range is the gun range corrected for all known variations from standard range table conditions which affect the projectile in flight, plus trunnion height and earth's curvature. It should be noted that the target motion does not enter into this computation, because the value of expected range applies to the point of fall of the projectiles and is to be used for comparison with the actual range to the point of fall.

Item p is the navigational range at the instant of firing. The most accurate and carefully calibrated radar should be used to obtain this figure.

Item q is obtained from the worksheet, using care in selecting the proper sign. Since in the example the target is closing, the range will decrease during the time of flight of the projectile.

Item r, the error of MPI, represents the actual difference between the position of the target at the instant of the fall of the projectiles and the mean point of impact of the several shots. MPI was discussed in greater detail in chapter 8.

For this use in postfiring analysis, the best available data on the points of fall of individual projectiles should be used. When a camera party is available, the best data is obtained by triangulation of aerial photographs. OVERS carry the plus (+) sign; SHORTS, -minus (-). An arbitrary value of +140 for error of MPI is used in figure B3.

Item s represents the actual range to the point of fall of the projectiles fired. Item t, therefore represents the otherwise unaccounted-for errors, the average value of which is used as ACTH in range.

B25. POSTFIRING ANALYSIS: COMPUTATION OF ARBITRARY CORRECTION TO HIT (DEFLECTION)

Item u (fig. B4) is the difference between the midpoint of the deflection scale and the actual scale reading. It is the number of mils between the plane through the LOS and the plane through the LOF at the instant the gun was fired. The sign is + if the scale reading is to the right of the midpoint and - if to the left. In the example the scale reading was 503.

Items v, w, and x—47.7, 109, and 40 yards, respectively in this example—are taken from the worksheet. The proper sign is important.

Item y is similar to item i and its value is zero in this example for the reason that was previously stated.

Item z, it will be noted, includes a conversion from yards to mils at the actual range.

Item aa, the expected deflection, consists of the deflection used, corrected for drift and those variations from standard range table conditions which affect the projectile while it is in the air. This item serves the same purpose in deflection as item o in range.

Item bb is obtained from the worksheet.

Item cc, is the error of the MPI in mils, obtained by photo triangulation or observation. If the MPI is right of the target, the sign is +, if left -. In the example, the error of the MPI was 2 mils left.

Item dd is the actual deflection of the MPI in mils. It is the perpendicular distance (converted to mils) from the vertical plane through

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the line of sight to the mean point of impact. This item is the deflection equivalent of item s above.

Item ee, the ACTH in deflection, is obtained by subtracting item aa from item dd. Like item t in range, it represents the errors otherwise unaccounted for. The ACTH in range and deflection represent the two values which are found through the processes of postfiring analysis.

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APPENDIX B

Part 2: Air-Density Nomogram

B1. INSTRUCTIONS FOR USING NOMOGRAM

Align (B) and (T) to get point on support (D). Align (D) with (R) to get error in yards due to change in density of air.

EXAMPLE:

Given:

Barometer	29.1 inches.
Temperature	80° F.
Range	8000 yards.

Result:

Error	+210 yards.

NOTE.—The best estimate of ballistic density to different altitudes is in very close, but not in exact agreement with standard density when surface conditions are standard. When surface density is not standard the disagreement is usually greater and is a function of surface density and maximum ordinate. Use of this nomogram will not give agreement with results obtained from column 12 of the range table and surface observations only, but it should be a more accurate figure because it takes into account the ratio between mean measured and standard density for the actual maximum ordinate obtained.

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APPENDIX C

ORDNANCE SAFETY PRECAUTIONS

C1. INTRODUCTION

The purpose of this appendix is to impress you with the need and reason for rigid adherence to safety precautions, and to point out the grave consequences that may result from violation of these precautions.

Article C2 lists safety precautions especially pertinent to the junior officer. Officers are particularly responsible for the military safety program. Ensigns, soon after commissioning, can expect to be in a position where they will have specific responsibilities for safety.

Article C3 gives actual case histories that clearly illustrate the safety problem. The cases included are but a few of many that could have been prevented. This article is abridged from OP 1014 (1st revision), entitled "Ordnance Safety Precautions, Their Origin and Necessity." OP 1014 will be revised in the near future. It will most likely contain current case histories and a compilation of revised safety precautions. OP 1014 (2nd revision) should be available at your first duty station when it is published. It will be well worth your while to read it when it becomes available.

C2. LIST OF SAFETY PRECAUTIONS

The list of safety precautions in this article is quoted primarily from chapter 20 of U.S. Navy Safety Precautions, OPNAV 34P1. A few are precautions issued by BuWeps and Forces Afloat. Chapter 20 of OPNAV 34P1 is in the process of being revised. It will be reissued as an OP. The Chief of Naval Operations will issue an OPNAV Instruction officially promulgating the Safety Precautions Ordnance Pamphlet as the authoritative document in this area, and indicating its applicability within the Naval establishment. This instruction will be printed as an integral part of the OP. Safety precautions 1-38 listed in this article are quoted from chapter 20 of OPNAV 34P1 and will be effective until superseded by the Safety Precautions (OP 3347).

It is emphasized that the following is NOT a complete listing of all ordnance safety precautions. The new Safety Precautions OP will have a complete list. It is important to remember that observance of all safety precautions is mandatory. In circumstances which conflict with their requirements, or if for other reasons changes in or additions to them are required, the responsible Navy authority must be informed. If there is any doubt as to the exact meaning of a safety precaution, an interpretation should be requested from the Bureau of Naval Weapons. Conditions not covered by the safety precautions may arise which, in the opinion of the commanding officer, may render further operation of the equipment unsafe. Under these conditions, nothing in the safety precautions should be construed as authorizing such further operations.

1. SAFETY DEVICES.—Safety devices provided shall always be used as designated to prevent possibility of accident, and shall be kept in good order and operative at all times. All instructions promulgated by competent authority to insure safe operation or handling of equipment shall be strictly observed. Such instructions include those in technical manuals, OP s, nameplates, and warning signs.

2. SAFETY WATCH FOR MOVING UNITS.—Whenever any motion of a power-driven unit is capable of inflicting injury on personnel or material not continuously visible to the person controlling such motion, the officer or petty officer who authorizes the unit to be moved by power shall, except at general quarters, insure that a safety watch is maintained in areas where such injury is possible both outside and inside the unit, and shall have telephone communication established and maintained between the station controlling the unit and the safety watch. These precautions are applicable to

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turrets, gun mounts, guns, directors, range-finders, searchlights, torpedo tubes, rocket launchers, and similar units. Under the conditions stated above, the station controlling shall obtain a report "all clear" from each safety watch before starting the unit. Each safety watch shall keep his assigned area clear and if unable to do so shall immediately report his unit fouled, and the controlling station shall promptly stop the unit until it is again reported clear.

3. WARNING SIGNAL.—In turrets and enclosed mounts, a warning signal shall be installed outside the turret or mount; and whenever power train is used, except at general quarters, the officer or petty officer in charge of the turret or mount shall cause warning signals to be sounded before using power and at intervals during its use.

4. CHANGES IN MATERIAL.—Changes, modifications in, or additions to ordnance material, or other material used in connection therewith, shall not be made without explicit authority from the bureaus concerned.

5. DESIGNATED USE OF EXPLOSIVES.—No ammunition or explosive assembly shall be used in any gun or appliance for which it is not designated.

6. DRILL AMMUNITION.—No other than drill ammunition shall be used for drill.

7. AA FIRING.—Except in action or when specifically authorized, antiaircraft guns shall not be fired at elevations greater than, or fuze settings less than, those prescribed in the current orders for Gunnery Exercises. When firing antiaircraft guns as such, all personnel not required to be exposed shall be kept under cover.

8. SUPERVISION.—As familiarity with any work, no matter how dangerous, is apt to lead to carelessness, all persons who may supervise or perform work in connection with the inspection, care, preparation, use, or handling of ammunition, explosives or ordance equipment—

(a) Shall exercise the utmost care that all regulations and instructions are rigidly observed.

(b) Shall carefully supervise those under them and frequently warn them of the necessity of using the utmost precaution in the performance of their work.

No relaxation of vigilance shall ever be permitted.

9. AMMUNITION TRANSFER. Except in case of emergency, ammunition shall not be transferred during fueling operations.

10. HIGH TEMPERATURE.—All ammunition, explosives, and powder shall be protected from abnormally high temperature. If so exposed, they shall be handled in accordance with current instructions of the Bureau of Naval Weapons. Permissible maximum storage temperatures shall be prescribed by the Bureau of Naval Weapons.

11. HANDLING.—To minimize the risk of fire, explosion, and damage to ammunition and its containers from accidental causes, ammunition shall be handled as little as practicable. As the action of denting thin-cased high-explosive ammunition is known to have caused detonation of the explosive in some instances, special care shall be exercised to insure that such ammunition is never struck, dropped, or bumped.

12. DEFECTIVE AMMUNITION.—Defective bomb type and thin-case ammunition shall be disposed of in accordance with current instructions of the Bureau of Naval Weapons.

13. DROPPING FUSED PROJECTILE.—A fuzed projectile, whether in a container or not, if dropped from a height exceeding 5 feet shall be dumped overboard in a manner conforming with regulations for dumping ammunition at sea except when practicable to turn the projectile in to a Naval Ammunition Depot. Such ammunition shall be handled with the greatest care.

14. STRIKING FUSED PROJECTILE.—Care must be used to avoid tapping or otherwise striking fuzed projectiles. This precaution is particularly applicable to attempts to loosen such a projectile in the cartridge case by repeated light blows of a mallet, unloading such a projectile wedged in the bore of a gun, and the striking of a projectile by the recoil of a gun or an ejected case.

15. SWITCHES.—The covers of switches, circuit breakers, etc., shall be kept securely closed while powder is exposed in the vicinity.

16. MAGAZINES.—Magazines shall be kept scrupulously clean and dry at all times. Nothing shall be stored in magazines except explosives, containers, and authorized magazine equipment. Particular attention shall be paid that no oily rags, waste, or other foreign materials susceptible to spontaneous combustion are stored in them.

17. NAKED LIGHTS.—Naked lights, matches, or other flame-producing apparatus shall never be taken into magazines or other spaces used primarily as magazines while these compartments contain explosives.

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18. EXCESSIVE HEAT.—Before performing any work which may cause either an abnormally high temperature or an intense local heat in a magazine or other compartment used primarily as a magazine, all explosives shall be removed to safe storage until normal conditions have been restored.

19. BLACK POWDER.—Black powder is one of the most dangerous of explosives and shall always be kept by itself. Only such quantities as will meet immediate needs shall be taken from the magazines. A container of black powder shall never be opened in a magazine nor in the vicinity of a container in which there is any explosive.

20. ALTERING AMMUNITION.—Ammunition shall not be altered nor shall fuzes or any other parts be removed or disassembled without explicit instructions from the Bureau of Naval Weapons.

21. TRIAL LOADING.—Live ammunition shall be loaded into guns for firing purposes only. Test or inspection of ammunition by fitting it into guns is prohibited, except when authorized by specific instructions of the Bureau of Naval Weapons.

22. POSITION OF BREECH.—The limiting position of the breech of the gun on recoil shall be indicated and the gun crew shall be instructed to keep clear.

23. UNLOADING GUN.—While a gun is being unloaded, all personnel not required for the unloading operation shall be kept at a safe distance from the gun.

24. RAMMING DEVICES.—Only approved ramming devices and methods shall be used in loading live cartridges. Any cartridge which does not freely and fully enter the chamber of the gun shall be carefully extracted and put aside, and no further attempt shall be made to fire such a cartridge.

25. "CEASE FIRE" WHEN GUN IS LOADED.—If a gun is loaded at the order "cease fire"—

(a) The gun shall be kept pointed and trained in a safe direction.

(b) The breech mechanism shall be kept fully closed.

(c) The gun shall normally be cleared by firing as soon as practicable.

26. FUSED PROJECTILE IN HOT GUN.—A loaded and fuzed projectile, seated in the bore of a gun that is hot from previous firing, presents a hazard, since detonation of the projectile is possible as a result of being heated. Whenever practicable, such projectile should be disposed of promptly by firing the round. Whether a gun is hot or cold, the risks attendant upon removing a loaded and fuzed projectile seated in the bore, by backing out are considered unwarranted except in the case of guns for which existing instructions specifically prescribe this procedure. Ordinarily, the round is disposed of by firing. If for any reason this is not possible, the round should be removed following the procedure outlined in OP 1591, "Clearing of Live Ammunition from Guns."

27. OBSTRUCTED LINE OF FIRE.—Ships shall cease the firing of any gun whose line of fire is endangering any objects other than the designated target. These objects include friendly ships and aircraft and own ship's structure together with the mounts and launchers and their barrels, fixed or moving. This stipulation applies to objects in the vicinity of the firing point, throughout the trajectory, and in the vicinity of the target. Turrets, mounts, guns, and launchers which are not firing, while others are firing, shall be trained and elevated if manned, or secured if unmanned, in a manner that will provide the greatest amount of safety from the firing. This position of greatest amount of safety of the unmanned mounts will generally be that position which the firing cutout cams of the firing mounts were cut to clear.

28. ARMED AMMUNITION.—Since it is not always possible to ascertain readily whether mines, depth chargers, rockets projector charges, and aircraft bombs have been inadvertently armed in storage or handling, all of these types, when fuzed or assembled with firing mechanisms, shall at all times be handled and treated as if armed, in strict conformity with the instructions for safeguarding against the inadvertent arming, firing, or launching of such ammunition.

29. REMOVING FUZE ARMING.—Fuze-arming wires or devices shall not be removed from the unarmed position until just before releasing or firing. Safety pins or other devices requiring removal before flight or firing shall not be removed until the ammunition has been loaded in racks, projectors, or launchers and not until after the arming wire or device has been put in place. Bombs, mines, depth charges, rockets, or projector charges not expended shall be made "safe" at the first opportunity in accordance with current instructions for the respective assemblies. When handling or unarming an accidentally armed fuze, the prescribed procedure shall be carefully followed.

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30. ELECTRONIC COMPONENTS.—Electric igniters, primers, or detonators, electrically fired rocket and guided missile motors, electric or electronic ordnance fuzes, including VT fuzes, shall not be stowed in the same compartment with, or be exposed within five feet of, any exposed electronic transmitting apparatus or exposed antenna or antennae lead, except where such electronic apparatus or antennae is a part of authorized test equipment of a weapon or is integral with a weapon containing such components, in which event special instructions pertinent thereto shall apply.

31. RECOVERING TORPEDO.—In recovering a torpedo in the water the propeller lock shall be put on at the first opportunity and kept on until the torpedo is safely landed.

32. TORPEDO TORCH POTS.—Because the filling material used in torpedo torch pots ignites spontaneously or forms poisonous gas when combined with water, or subjected to moisture, extreme care must be taken to follow existing Bureau of Naval Weapons instructions concerning the handling of torch pots.

33. ELECTRIC TORPEDOES.—The use of electric torpedoes involves hazards of mechanical injuries, electrical shock or burn, acid burns, and hydrogen explosion or combustion. Bureau of Naval Weapons instructions prescribe effective measures to prevent accidents and shall be rigidly adhered to at all times.

34. PYROTECHNIC MATERIAL.—Pyrotechnic material shall always be kept by itself in regular pyrotechnic storage spaces, if provided, or in pyrotechnic lockers on upper decks. In using it, only a minimum amount shall be exposed.

35. PATH OF EXHAUST.—All personnel shall keep clear of the possible exhaust path of missiles and rockets at all times.

36. ROCKET MISFIRES.—In case of rocket misfire, personnel shall not approach the rocket for at least 10 minutes, nor until firing circuits are known to be open. This, at the discretion of the commanding officer, is not obligatory in time of action.

37. BLOWBACK.—In firing small arms, machine guns, and submachine guns, whenever a blowback occurs the bore shall be examined for foul bore before firing another round.

38. SMALL ARMS.—Safety precautions in Army Regulations AR-385-63, Safety Regulations for firing ammunition, training, target, and combat shall apply to all small arms firing by Navy or Marine Corps personnel.

39. SUPERVISION OF PERSONNEL AND EQUIPMENT.—Whenever ammunition or explosives are being received, transferred, or stored, the work should be supervised by an officer or petty officer who is himself familiar with the rules for care and handling of explosives, and who sees that all persons engaged in the work are properly impressed with the necessity for exercising the greatest care.

40. SUPERVISORS' SAFETY DUTIES.—Supervisors have no authority to waive or alter station or BuWeps safety regulations nor to permit their violation by others.

41. DANGER.—Personnel engaged in handling or working with explosives should be repeatedly reminded by appropriate danger signs and oral admonitions that:

(a) Such substances are designed to explode, and are

(b) Always dangerous, and that

(c) A grain of explosive spilled from a container and ground between two hard surfaces (as between the nails in a shoe and a concrete or metal floor) is liable to cause an explosion which may be communicated to other explosives in the vicinity.

42. SAFETY INSTRUCTION.—All personnel in the naval service shall be carefully and frequently instructed in the safety precautions, methods of handling, storage, and the uses of all kinds of ammunition with which the ship , aircraft unit, or station may be supplied. All persons must distinctly understand that their safety as well as that of others depends on the intelligence and care exercised by themselves and by their fellow workers.

43. AMMUNITION DEFECTS.—Anyone knowing of defective ammunition or ammunition containers or handling devices or of any rough or improper handling or of any willful or accidental violation of the safety precautions, however slight, shall immediately report the fact to his immediate superior.

44. GUN AIMING.—Never point a gun at any person or object unless you intend to open fire on that person or object.

C3. CASES OF ORDNANCE CASUALTIES

In the following cases reference is made to the Bureau of Ordnance rather than to the Bureau of Naval Weapons because it was the cognizant bureau at the time the ordnance casualties occurred. The bureau changed names,

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so today the cognizant bureau is the Bureau of Naval Weapons.

1. In July 1945 an LCM gunboat was in an advanced Pacific harbor. Its crew had just completed installation of new cradles and adapters on the .50-caliber machine guns. A short trigger extension also had been installed without authorization from the Bureau of Ordnance. (Note precaution 4) A gunner's mate was engaged in testing the feeding of live ammunition into a port-side gun. (Note precaution 21) The harbor was occupied by several other small craft. The gun being tested pointed in the direction of a PT boat, 20 to 30 yards from the gunboat. (Note precaution 44)

As the gunner's mate was pulling the charging handle of the gun, it fired. An Ensign sitting on the bow of the PT boat was struck. The gun continued firing, narrowly missing other personnel, before it could be stopped. The Ensign was hit in the shoulder. If he had been in a slightly different position, perhaps standing instead of sitting, he might have lost his life.

Several precautions had been violated. The gun was pointed in a dangerous direction as it was loaded; the gun was being tested by loading it with live ammunition; and an unauthorized attachment to the gun had been made. The charging of the gun was enough to cause its discharge. The Chief of the Bureau of Ordnance commented that the casualty resulted primarily from the "use of an improper piece in a special experimental assembly for which the Bureau has issued no authorization."

INJURED: 1.

2. In 1948 a 3-inch 50-caliber mount was removed from a patrol craft for overhaul at a yard. The yard issued a job order to complete overhaul, including disassembly, inspection, and repair as required, assembly, and refilling of the recoil system with fluid. The mount was reinstalled prior to the end of the ship's availability, and the completed job order was signed and approved as satisfactory by the commanding officer.

About a week later, the gun was scheduled for firing. The Weapons Officer ordered a gunner's mate to complete the prefiring check-off, including a check of the recoil cylinder liquid. The gun was trained to 90° and elevated about 45° for firing. When the gun fired on the first round, the gun assembly recoiled, became detached from the slide assembly, backed out of the slide in the direction of recoil, and disappeared over the port side of the ship into the sea.

An immediate inspection showed that the recoil cylinder liquid was not at its proper level.

Secured to every gun mount fitted with a liquid-filled recoil system there is a metal plate with an engraved warning to the effect that the fluid level in the recoil system must be checked before every firing. (Recoil fluid level may be checked weekly if the gun is not being fired at least every week.) This precaution is published also in all Ordnance Pamphlets on gun mounts with liquid-filled recoil systems. Moveover, forces afloat have promulgated a regulation regarding liquid-filled recoil systems, in part as follows:

> "Before firing any gun, other than a saluting gun, in time of peace, the recoil cylinders shall be inspected and filled in the presence of the Weapons officer or assistant Weapons officers, . . .
>
> "Whenever there is a possibility of action, the commanding officer shall require all recoil and counterrecoil systems to be kept ready for immediate use and inspected as frequently as safety demands."

It is clear that recoil cylinder fluid level inspection is the cognizant officer's responsibility, even though the actual work is done by enlisted personnel. However, investigation revealed in this case that no liquid flowed from the recoil cylinder filling hole until the cylinder was depressed to a position of 8° elevation. In addition, the threads on the end of the piston rod and in the collar nut were so badly worn that they could not withstand the shock of recoil. The taper pin used to keep the collar nut in place had been bent and sheared off.

The Chief of the Bureau of Ordnance summed up the cause of the accident this way:

> "This casualty could have occurred even with perfect threads on the recoil rod and in the collar nut, if there were insufficient liquid in the recoil cylinder. From the evidence presented, it is not possible to determine whether worn threads, or lack of recoil liquid, or both, caused the casualty. Whatever the cause, personnel failure was basically responsible."

This loss could have been prevented if the personnel concerned had recognized and complied with the requirements promulgated in the publications and other sources that it was their duty to obey.

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MATERIAL LOSS: One gun.

3. In September 1944 a violent blast wiped out a naval ammunition depot. The Chief of the Bureau of Ordnance stated that the explosion resulted from "accidentally dropping or otherwise roughly handling a depth bomb."

According to eyewitnesses, a depth bomb was being transported on a standard two-wheeled stevedore truck. Apparently, because of carelessness, the bomb fell from the truck and exploded. One end of the depot became enveloped in flames. It spread to loaded charges in the building, but enough time elapsed to allow most personnel to escape. A huge blast then took place, blowing up the depot and its adjacent facilities. (Note precautions 8, 11 and 42)
DEAD: 10. INJURED: Over 60. MATERIAL DAMAGE: Destruction of depot.

4. Several months later, in December 1944, an explosion occurred at another naval ammunition depot. A war head exploded in an isolated magazine, an "igloo." The working crew of 7 enlisted men and 3 civilians were literally blown to bits.

The Board of Investigation was of the opinion that the explosion was caused either by "carelessness in handling by personnel, resulting in excessive swinging, causing one war head to bump against another" or by "lowering a war head to dunnage too rapidly." (Note precautions 8, 11 and 42.)
DEAD: 10. INJURED: None. MATERIAL DAMAGE: Slight.

5. An important lesson to learn about accidental explosions is that the force initiating explosions varies widely. In one instance, 12 TNT-filled bombs were dropped from a height of 2500 feet onto concrete. ONLY ONE EXPLODED, and that was a "low order" explosion. In contrast, a fall of a mere 6 inches set off a similar depth bomb. It is impossible to tell just how much rough handling a shell or a bomb will take before it explodes.

When men see explosives treated roughly without an explosion resulting, often it promotes carelessness. They begin to think, "This stuff can't go off." Safety procedures suffer. Ammunition is struck, dropped, mishandled. It didn't explode before, why should it this time? But it can—and it does.

Because safety precautions are violated once, or even more often, without accident, there is no reason to suppose that an explosion cannot take place the next time. Under identical conditions, one bomb may go off and another may not.

Proper handling and constant vigilance, therefore, are always necessary. Safety precautions demand this attention, and their observance is mandatory. These regulations should be learned early and never forgotten. When men forget, they seldom have another opportunity to learn. (Note precaution 41.)

The depth bomb which exploded after falling only 6 inches was aboard an aircraft carrier in 1945. Ordnance men were transferring Mk 54 bombs from one type aircraft to another being readied for patrol. An aviation ordnance man, second class, placed two bombs on a skid not fitted with a safety strap. He had to push the skid over an arresting gear wire. The skid tilted. Both bombs slid off and fell 6 inches to the deck. They struck tail vane first. One exploded.

Fifteen feet directly in front of the exploding bomb, a man working on a plane was struck and killed. Six others were injured. Torpex on the deck began burning, but was quickly extinguished. Two aircraft were damaged.

The Chief of the Bureau of Ordnance commented as follows:

> "Even though an improved method of securing depth bombs has been provided on skids Mk 1, it is this Bureau's opinion that the use of a safety strap would probably have prevented the accident." (Note precautions 1, 8, 11, 41, and 42.)

DEAD: 1. INJURED: 6. MATERIAL DAMAGE: Slight.

6. On 23 April 1945, an aviation machinist's mate third class was guarding 20-millimeter lockers as sentry. Contrary to orders, he removed a round of ammunition and attempted to dissemble it. Somehow, he caused the nose fuze to detonate and the projectile to explode. From the shock and from internal and external bleeding, he died. (Note precaution 20, 42.)
DEAD: 1.

7. On 20 December 1943, at a naval ammunition depot, a working party from a destroyer went into a magazine to obtain ammunition. Here is the testimony of a fireman.

> It's all my fault. The gunner's mate told us there was some French ammunition in the magazine, and I wanted to see it. I picked up a fuze out of a tin box and handed it to "P" asking him what it was, and he said he didn't know. Then I told him, "Well, I'll find out," and I pulled the wire out. It started to smoke, and I pushed the wire back in and then it exploded.

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Two men were injured; one lost a finger. Fortunately, the explosion was not communicated to other ammunition in the magazine. (Note precaution 20, 42.)
INJURED: 2.

8. Army and Navy personnel were loading fragmentation bombs onto an ammunition barge at a Pacific island in August 1945. The barge was moored to the end of a jetty filled with military and civilian personnel assigned there for duty. The Army personnel were loading bombs onto the starboard side of the barge. It was already partially full, with about 1300 bombs on it.

The men were becoming careless. During the day, single fragmentation bombs had been tossed distances of up to 7 feet from the jetty onto the barge. Such handling easily could detonate the bomb fuzes. That quite possibly could be what happened, for a large blast suddenly shot out from the barge. Flames and dense clouds of smoke arose, followed by other blasts. Debris was hurled 700 yards away. All personnel engaged in the loading were killed. (Note precaution 8, 42.)
DEAD: 28. INJURED: 16. MATERIAL DAMAGE: Heavy.

9. In September 1949, an amphibious landing demonstration was scheduled at a large eastern Atlantic port. Thousands of spectators attended. One part of the program called for a demonstration of demolition techniques. Live explosives were to be used against dummy obstacles. In order to simulate the burst of an antiaircraft projectile, the Ordnance Officer of one demolition team modified Emergency Identification Signals. Their pyrotechnic contents were removed, and a charge of one-half pound of TNT was substituted. A hand grenade detonator was tied or taped to the TNT. The alterations were made without any authorization from the Bureau of Ordnance. (Note precautions 4 and 5.)

Only 5 minutes prior to the demonstration, the Commanding Officer and the Executive Officer were told of the substitution. The Ordnance Officer, an experienced man, assured them that the signals had been test fired and were safe for firing. He was given permission to fire the modified signals.

Two signals fired satisfactorily. The third misfired and was removed from the projector. The fourth detonated within the projector, causing it to explode violently. A newspaper photographer was struck by a flying fragment and killed instantly. The Ordnance Officer, fatally injured, died 6 days later. Three others were hurt.
DEAD: 2. INJURED: 3

10. An accident aboard a cruiser in August 1942 caused a new precaution to be written, dealing with cook-offs, although a precaution dealing with the possibility of cook-offs already was in the Bureau of Ordnance Manual. In this accident a 5-inch 38-caliber projectile cooked-off, causing damage and deaths. The ship was then in action with the enemy. She was engaged in the bombardment of an island, then in possession of Japanese forces in the Pacific.

At the cease fire order, the left gun of mount one—along with other guns—remained loaded with an antiaircraft projectile. This gun had fired 210 rounds in the previous 13 hours. The Weapons Officer reported this situation to the Commanding Officer, who sought to unload the guns by firing. But the presence of aircraft, landing boats, and other friendly forces made firing extremely difficult. On any bearing, firing would have endangered other craft. In addition, because of transports, destroyers, and other ships the ship hardly could be maneuvered to a position at which the guns could be safely fired. As a result, the guns remained loaded.

About 1 hour after the cease fire order, the projectile in the left gun of mount one cooked-off and exploded. This was followed almost instantaneously by the explosion of the propellent charge.

The explosion split the breech housing longitudinally and blew out the breech mechanism. The floor plate under the gun was forced down into the upper handling room, crushing a shell passer there. Fragments of the breech mechanism and the projectile penetrated the projectile hoist and sprayed the mount. Five men were killed, 13 were wounded. The entire mount had to be replaced.

The Chief of the Bureau of Ordnance revised the safety precautions to include the present precaution. In addition, he made this comment on the accident:

> Simply removing the powder charge prior to the explosion of the projectile probably, in this case, would have prevented the bursting of the gun. However, it is believed that the above quoted instructions, emphasizing the necessity for ridding a hot gun of a live projectile with minimum delay, should make it inadvisable to suggest the use of

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that only partially effective procedure of removing only the charge.

Also, it it believed the emphasis now placed upon the necessity of promptly ridding a hot gun of a live projectile should make it sufficiently clear that this be done even if it is necessary to fire it perhaps "uncomfortably close" to other friendly ships in such an emergency.

The Commanding Officer of the cruiser undoubtedly did what seemed safest to him in the situation. Had he searched more thoroughly, however, he perhaps could have found some elevation and bearing which would have permitted firing, perhaps "uncomfortably close," but still safe. The accident seems almost unavoidable; nevertheless, it possibly could have been avoided. In any event, a loaded gun, hot from firing, is a hazard. The gun should be cleared by firing as soon as possible. Every effort should be made to fire the gun. The present precaution, resulting from this accident, now requires this action. (Note precautions 25 and 26.)

OP 1591 specifies in detail the prescribed procedures for clearing live ammunition from hot guns.

DEAD: 5. INJURED: 13. MATERIAL DAMAGE: Heavy.

11. On 14 June 1944, the after main battery director of a cruiser was training during a director check. The sightsetter left his assigned station without permission to go below. Suddenly a scream was heard. The sightsetter was found with his body jammed between the irregular projections of the director and the director shield, a space of from 5 to 8 inches. The sightsetter died from extreme multiple-injuries to his respiratory system.

(This case demonstrates the always present danger existing in the close confines around mounts, turrets, directors, etc. on Navy ships. (Note precautions 2 and 3.)

12. On 12 June 1952, drill projectiles were being sent up the hoist of a transport during a supply drill for 5-inch 38-caliber guns. The projectile hoist suddently failed. It would not hoist from the handling room to the mount. The mount captain opened the hoist and placed his right hand on the butt end of the projectile and his left hand on the ejector lever. He proceeded to twist the projectile in order to see if the fuze setting lugs were correctly engaged in the fuze pot.

The hoist operator then said that the hoist manual lever was stuck, at the same time placing his hand on that lever. The hoist cycled. The index and middle finger of the mount captain's right hand were shorn off.

A notice plate just above the door read DO NOT PLACE HAND IN HOIST. Instruction specified that power must be secured before any adjustments are attempted. (Note precaution 1.)

INJURED: 1.

13. On 1 July 1952, during a practice run of a destroyer a member of the gun crew of a 5-inch 38-caliber mount, was seated on the right gun captain's platform. The right gun was not to be fired. The man's left leg was placed beneath the right gun slide. At command, the mount elevated and the breech of the right gun descended and crushed the man's leg. It had to be amputated. (Note precaution 8—particularly the last sentence.)

INJURED: 1.

14. In May 1944 a destroyer was firing target practice in the Pacific. Suddenly a 5-inch 38-caliber gun fired directly into a 40-millimeter mount. Five men were killed, 18 others were hurt.

The direct cause of the accident was the failure of the gun's firing cutout mechanism to function properly. The key of a bevel gear had sheared off, which allowed the gear to slip on its shaft.

Since this condition had not been realized, the Board of Investigation concluded that the accident might have been prevented if the standard battery check-off list had been followed before the firing. A second possible preventive was the stationing of a safety observer as required by safety precautions; there was none so stationed. The Board expressed its opinion:

> If a safety observer had been stationed in 5-inch mount No. 3 and had properly performed his duties, the casualty might have been prevented since the safety observer would have observed through the check sight the danger of the 40-millimeter mount. (Note precautions 1 and 27.)

DEAD: 5. INJURED: 18. MATERIAL DAMAGE: Heavy.

15. On 1 October 1951, one 5-inch 38-caliber gun aboard a destroyer fired into another mount. As a result, 6 men were killed and 15 wounded.

In the investigation that followed, the Commanding Officer and the Weapons Officer stated that they were unaware that such an accident was possible. If they had known that one gun could fire into the barrel of another, they would have—as prescribed by the general safety

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precaution—issued additional precautions intended to prevent such an accident. As it was, no warnings or precautions dealing with this hazard had been posted. (Note precaution 27.)

The mount captain had not complied adequately with safety requirements, for he did not use his sight port to observe the line of fire to insure that it was safe. The gun of mount two, the mount hit, was trained and elevated to a "ready" position. In this position, the gun barrel could be in the line of fire of mount one. Mount two was not firing; it was not to fire until after mount one had completed its firing. For safety, therefore, mount two should have been held "ready" at its normally secured position at zero degrees train. If it had been held "ready," no accident would have occurred.

The cut-out cam is designed to prevent firing into fixed objects of the ship's structure. These include turrets, mounts, launchers, torpedo tubes, and cranes in their STOWED POSITIONS ONLY. Personnel must see that such items do not endanger the line of fire. In this case, any one of several responsible individuals—the Commanding Officer, the Weapons Officer, the Control Officer, the mount captain, or a safety observer—could have prevented the accident. No mechanical defect existed. The failure was human.

DEAD: 6. INJURED: 15.

At the time of this casualty, the precaution read:

> When using director train while firing at gunnery exercises, an observer from the firing ship for each gun or turret shall cause the firing circuit to be broken whenever the gun or turret is trained dangerously near any object other than the designated target.

The precaution has since been revised to its present form (see precatuion 27), to remove any doubt as to its meaning. The change was made partly as a result of this case.

16. A Marine found a 37-millimeter dud on a firing range. He turned it in to the Quartermaster tent. Later, a sergeant came into the tent and saw the dud. In apparent disregard of orders and safety, he aimed the shell at a hole in the wooden floor of the tent and dropped it. He commented that he would make "a pretty good bombardier." He dropped the shell at least six times. Finally, inevitably, it exploded. The sergeant was killed. Two others were injured. (Note precaution 8, 42.)

DEAD: 1. INJURED: 2.

17. Aboard a destroyer in May 1949, a gunner's mate was cleaning and chipping paint off a 40-millimeter gun mount. For some reason, and in violation of existing orders, he removed the cover plate from the train motor control switch box. Perhaps he meant to clean it.

Minutes later he was found on the deck, dead. He had been electrocuted by a circuit of 440 volts. Artificial respiration was of no help. Actually, the switch box was part of the fire control circuit and the gunner's mate was not authorized to open it. Even if he thought he was, he certainly should not have forgotten this precaution issued to the ship:

> When work is done on any circuit, the switch controlling that circuit should be opened and a danger sign secured to it.

The danger sign should contain sufficient instructions to prevent anyone but the proper individual from reenergizing the circuit. (Note precautions 1 and 8.)

18. Although there was no actual violation of a safety precaution, the following case shows clearly the need for precautions which require setting depth charges on SAFE as soon as possible. (See precautions 28 and 29.) In December 1942, a high-speed minesweeper was acting as an escort ship. The ships ran into a very stormy sea. Depth charges, which apparently had been set at various depths in preparation for a submarine attack, became endangered when a starboard paravane broke loose and swung free. A gunner's mate managed to set all charges on SAFE except the two outboard charges. Because of the rough sea and the design of the rack, it was impossible for him to reach these two charges.

A blow from the free-moving paravane caused the releasing device on the depth charge rack to release several charges, which went overboard. One or both of the charges not set on SAFE blew close to the ship's stern. The after end of the ship broke off forward of the after deck house, and sank. The after engine room flooded. The ship was in danger of sinking. The Commanding Officer gave the order to abandon ship. All personnel were removed to another ship. No one was seriously hurt. Not long after, the minesweeper sank.

MATERIAL DAMAGE: Loss of one ship.

19. The danger of placing ammunition near inflammable fuel is illustrated by an accident

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which took place in the Netherlands West Indies in 1943. (Note precaution 9.)

Two British depth charges had been placed on the end of a Dutch Coast Guard Station pier. Within a building on the pier were a "lauser" gasoline powered motor and a can holding gasoline. From causes unknown, a fire started in the building. It spread rapidly to the end of the pier.

The depth charges went off in an explosion which demolished the pier structure. Sixteen men who were working at a nearby construction project were injured. One of them died later from his injuries.

DEAD: 1. INJURED: 15. MATERIAL DAMAGE: Heavy.

20. In September 1963, a DD was moored in a nest with five DDs and one AD, third ship outboard, at Newport, R. I. During the morning, extensive system alignment checks were being conducted on the torpedo fire control system in preparation for a test firing of dummy torpedoes the following day. The crew, which was being directed by a Torpedoman's Mate 2, had been working long hours the previous week attempting to get the system in proper working condition for the forthcoming exercises. They had had trouble clearing electrical grounds from the firing circuits of numbers 2 and 4 tubes. While conducting tests during the previous week and that day, it had been necessary for them to remove the torpedo from each tube before firing an air slug electrically, then to reinsert it after firing. One of the torpedoes (the one that had been in number 2 tube) was left on the rack behind the tube. The crew had difficulty clearing the ground from number 2 tube so they decided to switch their efforts to number 4. They corrected the ground in number 4 tube but failed to remove the torpedo. Meanwhile, the ship experienced a shore power failure. This failure did not stop the work on number 4 tube but did add somewhat to the existing confusion. Finally, after the tube was charged with air, it was electrically test fired by the TM 2 (who forgot number 4 was loaded). Result—the #4 torpedo, which was a warshot, was fired against the superstructure, frame 81, of the DD alongside. Damage to the DD was minor. The torpedo, however, had to be removed from service.

The findings of the Board of Investigation were that:

1. The firing of the torpedo from tube number 4 occurred as a result of personnel error.

2. The temporary loss of ship's power for a period of one hour and ten minutes prior to the incident, coupled with numerous pulling and reinserting of torpedoes from their tubes in the days preceding the incident, were distracting influences which might have "dulled" the attention to detail which a transmission check demands. (Note precaution 8.)

The TM 2 was wrong in what he did (note precaution 40), but it appears he could have used some backup supervision. If his leading division petty officer or his division officer had been on deck during this crucial test of the tube, chances are that the accident would not have happened. They should make it a point to be at the places where work is going on, at the right time. That way they have a much better chance of catching possible trouble sources before it is too late.

MATERIAL DAMAGE: Loss of one torpedo.

C4. SUMMARY

The following report of a Navy board clearly expresses the lesson this appendix strives to emphasize:

It is unquestionable that any intelligent action in prevention of casualties must be based on a thorough knowledge and understanding of safety precautions. All personnel concerned must thoroughly understand how and why (safety precautions) actually apply in practice, as well as have a knowledge of what (safety precautions) are. Constant vigilance must be exercised to assure that they are at all times carried out in every detail; any violations or tendency to veer from this vigilant attitude must be abruptly checked at the time it occurs.

Inasmuch as the safety precautions are generally understood by all hands to be one of the primary laws of self-preservation, cases of willful violation of them are rare. It is, rather, ignorance of their existence and application, or a slacking off of their meticulous observation bred from an overconfidence in nonoccurrence of casualties, that causes violation of them.

There can be no law against casualties nor can they be ordered out of existence. This can obviously not be done under conditions where the human element is involved. However, a large percentage of casualties can be very definitely and positively eliminated by a proper overhaul, inspection, and test of material and by proper and sufficient drill of personnel in handling their gear.

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